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The Type of Fortificant and the Leaf Matrix Both Influence Iron and Zinc Bioaccessibility in Iron-fortified Green Leafy Vegetable Sauces from Burkina Faso

C. Icard-Vernière, C. Picq, L. Courbis, and C. Mouquet-Rivier

Leafy vegetable sauces from Burkina Faso were assessed as a potential vehicle for food fortification. First, iron and zinc bioaccessibility were measured by dialysability method in amaranth and Jew’s mallow sauces and in traditional whole dishes consisting of maize paste plus leafy vegetable sauces. Iron dialysability and solubility were higher in amaranth than in Jew’s mallow sauce, pointing to a marked effect of the matrix. Iron dialysability was hardly affected by the maize paste contrary to zinc dialysability, which was reduced. Second, iron and zinc bioaccessibility was assessed in the same sauces fortified with NaFeEDTA or iron sulfate. Added iron, i.e. iron supplied by fortification, represented 60% of total iron at the low fortification level and 80% at high level. In amaranth sauces with the high level of fortification using NaFeEDTA and iron sulfate, fractional dialysable iron reached respectively 66% and 26% compared to only 8.1% in the unfortified sauce. Similarly, in Jew’s mallow sauces, fractional dialysable iron was 57% and 5% respectively with NaFeEDTA and iron sulfate and less than 1% in the unfortified sauce. Concomitantly, fractional dialysable zinc increased by respectively 20% and 40% in amaranth and Jew’s mallow sauces fortified with NaFeEDTA whereas it remained unchanged with iron sulfate. Iron fortification could be an efficient way to greatly increase the available iron content of green leafy vegetable sauces and for this purpose NaFeEDTA is more effective than iron sulfate whatever the food matrix.

1 Introduction

Traditional diets in African low-income countries rely on starchy foods prepared from staple crops, accompanied by a relish, sauce or soup, consisting of vegetables and often leafy vegetables, beans or groundnuts, fats and oils, condiments and spices. Leafy vegetables are frequently consumed, almost daily, mainly as sauces in Western Africa, as they make starchy foods more palatable and are a well-known source of micronutrients. They could thereby be used in food-to-food fortification programs to help fight widespread micronutrient deficiencies in low-income countries. In Burkina Faso in 2010, anemia prevalence was 88% in children aged 6-59 months, and almost 49% in women aged 15-49 years. Anemia can be caused by several factors like parasitic infections, bleeding, chronic diseases... and about half cases are due to iron deficiency. Data about zinc deficiency are scarce and not available in Burkina Faso. However, it is well recognized that growth retardation is one of its main consequences, and its national prevalence in Burkina Faso is 34.1%. Leafy vegetables could thus supply iron and are a good, available, cheap and natural source of vitamin C and provitamin A. As outlined by some authors, leafy vegetables could play a role in anemia prevention thanks not only to the presence of iron but also to their significant ascorbic acid content, which is known to promote the absorption of soluble non-haem iron by chelating the iron thus maintaining it in the ferrous absorbable soluble form. Despite consumption patterns that differ among households in different countries, this natural resource, which is harvested in the wild or cultivated, can contribute to food and nutrition security. The consumption of leafy vegetables should thus be encouraged. Food processing may affect their nutritional value: cooking has no effect on iron and zinc content but reduces ascorbic acid content and may thus affect the bioavailability of these micronutrients; it also increases beta-carotene bioavailability by softening the plant structure.

Few studies have assessed the bioavailability of iron and zinc in leafy vegetable dishes. A higher in vitro available iron fraction was measured in leafy vegetables from India or leafy vegetable-based meals compared to meals based on cereals or legumes. Highly variable in vitro availability of iron, ranging from 6 to 44% in 13 crude leafy vegetables in India, was also reported, due to interactions between the components in the leaves studied. In an in vivo iron absorption study of a typical Burkinabe meal, iron absorption from maize paste eaten with a traditional leafy vegetable sauce with amaranth leaves was compared to maize paste plus iron-improved sauces containing extra leaves of amaranth or Jew’s mallow (also called jute). However in that study, despite higher iron content per serving in the iron-improved sauces, the increase in the proportion of leafy vegetables in the sauce compared to the traditional recipe did not provide additional bioavailable iron.

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The high concentration of phenolic compound in the leafy vegetables was assumed to impair iron bioavailability in these dishes. Moreover, the ascorbic acid content - known to be an iron-absorption enhancer - was close to zero in the sauces, due to the long cooking required to soften the texture of the leaves. As long as most people in Burkina Faso and other sub-Saharan countries cannot afford to include animal source foods in their diet, the fortification of sauces with micronutrients could be a temporary solution. Ferrous sulfate and sodium iron EDTA are often used as fortificants. Ferrous sulfate is the most frequently used and the cheapest, water-soluble iron fortificant. EDTA is known as a strong chelator of divalent cations and then protects iron against chelation by iron-absorption inhibitors. Therefore, sodium iron EDTA is recommended in high-phytate foods, such as cereal based products because its absorption is greater than other iron fortificants. In food with low phytate content, its absorption is equivalent but it has other technical advantages. In this context, the aim of our study was to assess the bioaccessibility of iron and zinc in the same amaranth and Jew’s mallow sauces as in the previous study, alone or mixed with a proportion of maize paste, as usually consumed. The effect of fortification of these sauces with either iron sulfate or sodium iron EDTA on iron and zinc bioaccessibility was analyzed.

2 Materials and methods

Dish preparation

LV sauces and maize paste were prepared as previously described with some modifications described below.

Sauce ingredients

Approximately 5 kg of leaves of Amaranth (Amaranthus cruentus) and Jew’s mallow (Corchorus olitorius) were purchased from local gardeners in Ouagadougou (Burkina Faso). They were carefully washed three times with tap water and once with deionized water to remove any trace of soil or dust that could lead to iron contamination, before freezing. Leaves were kept frozen until analysis and preparation of the sauces. Stock cubes, potash, groundnut paste, dried fish, soumbala (fermented beans used as a relish) were purchased in a local market in Montpellier just before use. Ingredients from the same batch were used for each batch of sauce.

Sauce preparation

Sauces were prepared in the laboratory according to a standardized recipe to obtain sauces with 20% dry matter using the same proportion of ingredients except for the type of leaves (Table 1). The iron compounds used for the fortification of amaranth and Jew’s mallow sauces were ferrous sulfate and sodium iron ethylenediaminetetraacetate (NaFeEDTA) kindly provided by DSM (Heerden, The Netherlands). The levels of fortification were chosen to target a total iron content of 8 mg (level L1) and 16 mg (level L2) per 100 g of sauce taking into account mean intakes of respectively 166 and 66 g of sauce per meal by women of childbearing age and young children in Burkina Faso and a targeted contribution to iron recommended nutrient intake (RNI) of 50%. Corresponding quantities of iron compounds were carefully weighed, added to the diluted sauces contained in a large bottle, and homogenized on a shaking table for 1 h at 4 °C. Aliquots (50 mL) of fortified sauces were then frozen until use.

Preparation of « tô » cereal paste

A cereal-based thick paste whose local name is « tô » was prepared from decorticated maize flour with a final dry matter content of 22%-23% according to the traditional recipe from Burkina Faso but with quantities adapted for laboratory use. The phytate content of this flour was low (around 130 mg phytate/100g DM).

Preparation of dishes of tô and sauces ("whole dishes")

Mixes of sauces plus tô, representing typical dishes eaten in sub-Saharan Africa and called “whole dish” in this paper, were prepared at a proportion of 2:1 on a fresh basis, as traditionally consumed and used for micronutrient bioaccessibility measurements. Mixes were homogenized with an Ika Ultra-Turrax T25 (Staufen, Germany) before use.

Analytical methods

DM contents were determined by oven drying at 105 °C to constant weight. Iron and zinc were extracted with a closed-vessel microwave digestion system (ETHOS-1, Milestone, Italy) and analyzed using a Perkin-Elmer AAAnalyst 800 Atomic Absorption Spectrometer (Waltham, USA). Standard reference materials BCR-191 Brown Bread and BCR-191 Brown Bread (IRMM- Institute for Reference Materials and Measurements, European Commission) were used as controls with iron SpectAA measurements. The coefficients of variation obtained with these two reference materials were 5.74 and 5.62% respectively, with distances from the reference value of -1.24% in the case of white cabbage and -4.62% in the case of brown bread.

Iron and zinc bioaccessibility, also called availability, was determined using dialysability used to obtain information about digestion of the food and release of the minerals from the food matrix. Iron and zinc bioavailability depends on both food and host factors, and thus its assessment requires the use of in vivo methods on humans, to consider each step involved: (i) digestion and release of nutrients from the foods, (ii) uptake followed by (iii) absorption into the enterocytes, (iv) retention and (v) transport to tissues or storage sites for use and/or storage. As preliminary screening tools, in vitro methods including solubility, dialysability and simulated gastrointestinal digestion or Caco-2 cells have been
Table 2: Bioaccessibility of iron and zinc in amaranth and Jew’s mallow sauces or in the whole dishes comprising sauce plus tô

<table>
<thead>
<tr>
<th>Sauces</th>
<th>Total mineral (mg/100g)</th>
<th>Dialysable fraction (%)</th>
<th>Soluble fraction (%)</th>
<th>Insoluble fraction (%)</th>
<th>Dialysable fraction (mg/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amaranth</td>
<td>3.08 ± 0.21</td>
<td>8.1 ± 1.4</td>
<td>13.3 ± 1.1</td>
<td>78.7 ± 1.0</td>
<td>0.25 ± 0.05</td>
</tr>
<tr>
<td>Jew’s mallow</td>
<td>3.06 ± 0.24</td>
<td>0.9 ± 0.7</td>
<td>3.1 ± 0.3</td>
<td>96.0 ± 1.0</td>
<td>0.03 ± 0.02</td>
</tr>
<tr>
<td>Amaranth + tô</td>
<td>1.07 ± 0.09</td>
<td>6.8 ± 1.7</td>
<td>14.7 ± 1.0</td>
<td>78.6 ± 2.7</td>
<td>0.07 ± 0.02</td>
</tr>
<tr>
<td>Jew’s mallow + tô</td>
<td>1.12 ± 0.00</td>
<td>2.1 ± 0.3</td>
<td>3.4 ± 0.6</td>
<td>94.5 ± 0.3</td>
<td>0.02 ± 0.00</td>
</tr>
<tr>
<td>Zn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amaranth</td>
<td>0.60 ± 0.00</td>
<td>58.8 ± 11.3</td>
<td>0.0 ± 0.0</td>
<td>41.2 ± 3.7</td>
<td>0.38 ± 0.07</td>
</tr>
<tr>
<td>Jew’s mallow</td>
<td>0.51 ± 0.09</td>
<td>32.0 ± 6.9</td>
<td>1.3 ± 1.6</td>
<td>64.9 ± 4.9</td>
<td>0.17 ± 0.05</td>
</tr>
<tr>
<td>Amaranth + tô</td>
<td>0.11 ± 0.01</td>
<td>46.5 ± 2.8</td>
<td>4.6 ± 4.2</td>
<td>43.2 ± 8.0</td>
<td>0.05 ± 0.04</td>
</tr>
<tr>
<td>Jew’s mallow + tô</td>
<td>0.10 ± 0.00</td>
<td>46.3 ± 9.0</td>
<td>0.0 ± 0.0</td>
<td>58.5 ± 11.6</td>
<td>0.05 ± 0.01</td>
</tr>
</tbody>
</table>

Results are means of 3 measurements ± standard deviation; values in one column for the same mineral with different superscript letters are significantly different (p < 0.05).

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These methods are simpler, less expensive and give models of iron and zinc absorption that can be used to develop hypothesis. We used an appropriate in vitro procedure with modifications and including first the determination of the titratable acidity of samples and a simulated digestion. Micronutrient bioaccessibility was measured at least in triplicate on samples of unfortified sauces, fortified sauces, and whole dishes prepared “as eaten” i.e. freshly cooked in the manner they are normally consumed. Samples were homogenized with ultrapure water to obtain a DM content of 9-10% in sealed glass flasks and brought to 37 °C in a water bath. Alpha-amylase (20 µL) from Bacillus licheniformis (Sigma A-3403-1MU) was added to the samples, which were then incubated at 37 °C for 5 min. The pH was adjusted to 2.0 with 1 M HCl; 1 mL of peptic solution was then added (Sigma, P-7000, 14900 u/mL in 0.1 M HCl) and the samples were incubated horizontally for 1 h at 37 °C in a shaking water bath. Aliquots (40 g) of each peptic-digested sample were then transferred in separate large tubes for the intestinal digestion. To gradually increase the pH to mimic intestinal digestion, a dialysis bag (Spectra/por I dialysis tubing, MCO 12-14kDa) containing 20 mL of the PIPES (piperazine-N,N'-bis-[2-ethanesulfonic acid] sodium salt) buffer (Sigma, P-3768) of the previously determined molarity was added. The pH was gradually increased to mimic intestinal digestion, a dialysis bag so that dialyzable iron was diffused into the dialysis bag. During incubation, dialyzable iron was diffused into the dialysis bag so that the same concentration was reached on both sides of the membrane. The dialysis bags were then removed and washed with pure water. Their contents were weighed. The digestion mixtures remaining in the tubes were centrifuged at 10,000 g for 15 min at 4 °C to separate the insoluble and soluble iron fractions, respectively, in the pellet and supernatant. Thus, the sum of dialyzable, soluble non-dialyzable and insoluble fractions should be equal to the total amount of mineral in the sample before digestion.

The sum of dialysable, soluble non-dialysable (SND) and insoluble fractions should thus be equal to the total amount of iron in the sample before digestion. Each fraction was calculated on the basis of the total iron or zinc recovered at the end of digestion:

Dialysable Fe or Zn % = C_D/(C_D + W_D) x 100 (1)
SND Fe or Zn % = W_I/(C_D + W_D + W_S) x 100 (2)
Insoluble Fe or Zn % = W_I/(C_D + W_D + W_S) x 100 (3)

where C_D, W_D and C_I are iron concentrations (µg/100 g) and W_S, W_D and W_I are the weights (g) of the dialysate, supernatant, and pellet, respectively. The iron contents of each fraction were analyzed as described above. Results are expressed as a percentage (fractional iron) of the total iron in the food.

3 Results

Iron and zinc bioaccessibility in the sauces and in the whole dishes

Total iron contents in amaranth and Jew’s mallow sauces were similar and 5 to 6 times higher than total iron contents in both sauces, which were very low (Table 2). In the whole dishes, the addition of tô resulted in a decrease in iron and zinc contents. This was due to a “dilution” effect of the already low iron and zinc contents in maize tô (0.15 and 0.10 mg/100 g respectively).

In the amaranth sauce, dialysable iron content was 0.25 mg/100 g, which represented 8.1% of total iron. In the whole dish prepared with this sauce, the behavior of iron was not significantly modified: which represented 8.1% of total iron. In the whole dish prepared with this sauce, the behavior of iron was not significantly modified.
Figures 1a and 1b: Distribution of native and added iron in amaranth and Jew’s mallow sauces fortified (or not) with NaFeEDTA or iron sulfate. L1 and L2 are two levels of fortification, L1 = 8 mg of iron/100 g of sauce; L2 = 16 mg of iron/100 g of sauce.

lower than in the sauce, giving a dialysable iron content about 3.4 times lower. The percentages of soluble and insoluble iron were also similar, as if the difference between the amaranth sauce and the whole dish was only due to the dilution effect of adding tô. In the Jew’s mallow sauce, the dialysable iron content was 0.03 mg/100 g of sauce, i.e. much lower of that of the amaranth sauce, even though total iron content was similar. Indeed, the dialysability of iron was 10 times lower than in amaranth sauce. The soluble non dialysable iron fraction was also much lower, and the insoluble iron fraction was significantly higher in the Jew’s mallow sauce. When mixed with tô in a whole dish, the percentage of dialysable iron was slightly but not significantly higher than in the Jew’s mallow sauce alone. Their dialysable iron contents were similar, as if the higher dialysability compensated for the “dilution” effect of tô. Soluble and insoluble iron percentages also resembled those in the amaranth sauce and whole dish. It thus appears that maize tô hardly influences the amount of dialysable iron supplied by the Jew’s mallow sauce.

Despite similar total zinc contents, the percentage and concentration of dialysable zinc were almost twice higher in the amaranth sauce than in the Jew’s mallow sauce. Almost two-thirds of the total zinc in the amaranth sauce was dialysable, i.e., much higher than iron. In the whole dishes with amaranth or Jew’s mallow sauces, the distribution in the different fractions was much the same, i.e. about half of total zinc was dialysable, and the remaining zinc was insoluble. The percentage of soluble zinc in the sauces was negligible and in the whole dishes, was less than 5%. Dialysable zinc content was 3.6 to 7 times lower in the whole dishes due to a simple dilution effect of mixing the sauce with the tô.

Iron and zinc bioaccessibility in fortified sauces
Fortification of amaranth or Jew’s mallow sauces with NaFeEDTA or Fe sulfate led to total iron contents that are consistent with targeted values (Figs. 1a and 1b): in both sauces, the total iron contents obtained with both fortificants did not differ significantly, whatever the fortification level. Added iron, i.e. iron supplied through fortification, represented respectively 60% and 80% of total iron in the sauces with L1 and L2 fortification levels. As NaFeEDTA or Fe sulfate did not contain zinc, the total zinc content of the fortified sauces remained unchanged after fortification. The percentage of dialysable iron in the fortified amaranth sauces was significantly higher than that in the unfortified sauce (Figs. 2a and 2b): at levels L1 and L2, it was respectively 6% and 8% times higher with NaFeEDTA, and 2.5% and 3.2% higher with iron sulfate. The marked effect of NaFeEDTA, and to a lesser extent that of iron sulfate, on iron dialysability was also measured in fortified Jew’s mallow sauces: at both levels L1 and L2, the percentage of dialysable iron was respectively 4.8% and 64.5% higher in the fortified sauces compared to the unfortified sauce.
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For their respective unfortified sauces, the percentages of NaFeEDTA, and 3 and 6 times higher with iron sulfate. Compared to fortified with Fe sulfate or not fortified. As a result, dialysable zinc (Table 4), due to the absence of zinc in the fortificants used. Fortification of sauces had also a huge effect on Total zinc contents

Results are means of 3 measurements ± standard deviation; values in one column for the same sauce with different superscript letters are significantly different (p < 0.05). L1 and L2 are two levels of fortification, L1 = 8 mg of iron/100 g of sauce; L2 = 16 mg of iron/100 g of sauce

Table 3: Bioaccessibility of iron in fortified amaranth and Jew’s mallow sauces

<table>
<thead>
<tr>
<th>Sauces</th>
<th>Total Fe (mg/100g)</th>
<th>Dialysable Fe (mg/100g)</th>
<th>Soluble Fe (mg/100g)</th>
<th>Insoluble Fe (mg/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfortified</td>
<td>3.08 ± 0.21</td>
<td>0.25 ± 0.05</td>
<td>0.41 ± 0.01</td>
<td>2.42 ± 0.19</td>
</tr>
<tr>
<td>Amaranth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe sulfate L1</td>
<td>7.87 ± 0.28</td>
<td>1.62 ± 0.14</td>
<td>2.34 ± 0.13</td>
<td>3.91 ± 0.21</td>
</tr>
<tr>
<td>Fe sulfate L2</td>
<td>15.98 ± 1.19</td>
<td>4.17 ± 0.29</td>
<td>4.72 ± 0.19</td>
<td>6.97 ± 0.75</td>
</tr>
<tr>
<td>NaFeEDTA L1</td>
<td>6.82 ± 1.49</td>
<td>3.29 ± 0.83</td>
<td>0.66 ± 0.14</td>
<td>2.87 ± 0.58</td>
</tr>
<tr>
<td>NaFeEDTA L2</td>
<td>14.87 ± 1.77</td>
<td>9.87 ± 1.50</td>
<td>1.02 ± 0.11</td>
<td>3.98 ± 0.16</td>
</tr>
<tr>
<td>Jew’s mallow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unfortified</td>
<td>3.06 ± 0.24</td>
<td>0.03 ± 0.02</td>
<td>0.09 ± 0.01</td>
<td>2.93 ± 0.24</td>
</tr>
<tr>
<td>Fe sulfate L1</td>
<td>8.42 ± 0.50</td>
<td>0.22 ± 0.01</td>
<td>0.52 ± 0.01</td>
<td>7.68 ± 0.51</td>
</tr>
<tr>
<td>Fe sulfate L2</td>
<td>16.48 ± 0.14</td>
<td>0.09 ± 0.01</td>
<td>1.28 ± 0.04</td>
<td>14.31 ± 0.21</td>
</tr>
<tr>
<td>NaFeEDTA L1</td>
<td>7.91 ± 1.44</td>
<td>3.46 ± 0.66</td>
<td>0.02 ± 0.04</td>
<td>4.55 ± 0.70</td>
</tr>
<tr>
<td>NaFeEDTA L2</td>
<td>15.07 ± 0.92</td>
<td>8.67 ± 0.70</td>
<td>0.01 ± 0.00</td>
<td>6.57 ± 0.28</td>
</tr>
</tbody>
</table>

Results are means of 3 measurements ± standard deviation; values in one column for the same sauce with different superscript letters are significantly different (p < 0.05). L1 and L2 are two levels of fortification, L1 = 8 mg of iron/100 g of sauce; L2 = 16 mg of iron/100 g of sauce.


da, b, c, d, e, f, g, h, i, j, k, l, m, n, o, p, q, r, s, t, u, v, w, x, y, z.

4 Discussion

In our study on sauces or on whole dishes of sauce and tō, we showed that the difference in iron bioaccessibility between the amaranth sauce and the corresponding whole dish was probably due to the dilution caused by adding tō. We also showed that iron was much more dialysable and soluble in amaranth sauce than in Jew’s mallow sauce whereas the percentage and concentration of insoluble iron were significantly higher in the Jew’s mallow sauce. That is why the dilution effect due to the addition of tō led to a decrease in iron bioaccessibility in the whole dish made from tō + amaranth sauce compared to the sauce alone, while it increased in the case of Jew’s mallow. This difference between the two leaf species may be related to their biochemical composition, particularly of their fibres. It is known that Jew’s mallow leaves are rich in water soluble mucilage that give rise to viscous hydrocolloid solutions. Indeed, the Jew’s mallow sauce is characterized by its slimy texture, which can be explained by this high water soluble mucilage content. Mucilage is a non-starch polysaccharide that contains uronic acids, mainly glucuronic and galacturonic acid. As pectin also contains uronic acids that have mineral-binding properties due to their carboxyl groups, we hypothesize that the mucilage in Jew’s mallow leaves binds divalent cations such as iron or zinc, which may explain their lower mineral bioavailability compared to amaranth sauce. As the pKa of glucuronic acid ranged between 2 and 4, the carboxyl groups may be deprotonated as the pH increases during digestion and then may bind part of the iron, as shown for pectin, a polysaccharide rich in polygalacturonic acid. However, such a difference between amaranth and Jew’s mallow sauce was not found in an in vivo absorption study in which both sauces exhibited the same absorption rate of 4.9%. As reviewed recently, the negative effects of fibers on mineral bioavailability observed in vitro are not always confirmed in vivo. Other chelating factors may also have an effect on the bioaccessibility of iron and zinc in the amaranth and Jew’s mallow sauces. In the previously cited study, the authors explained that the low iron absorption level obtained for the improved sauces containing extra leaves could be due to their higher content in phenolic compounds, known to inhibit iron absorption, and that may have played the role of a
Table 4: Bioaccessibility of zinc in fortified amaranth and Jew’s mallow sauces

<table>
<thead>
<tr>
<th></th>
<th>Total Zn (mg/100g)</th>
<th>Dialysable Zn (%)</th>
<th>Soluble Zn (%)</th>
<th>Insoluble Zn (%)</th>
<th>Dialysable Zn (mg/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unfortified</td>
<td>0.60 ± 0.00</td>
<td>a</td>
<td>62.8 ± 12.1</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td></td>
<td>Fe sulfate L1</td>
<td>0.53 ± 0.06</td>
<td>a</td>
<td>55.0 ± 8.0</td>
<td>1.2 ± 1.1</td>
</tr>
<tr>
<td></td>
<td>Fe sulfate L2</td>
<td>0.63 ± 0.03</td>
<td>a</td>
<td>53.6 ± 2.5</td>
<td>0.8 ± 1.3</td>
</tr>
<tr>
<td></td>
<td>NaFeEDTA L1</td>
<td>0.48 ± 0.03</td>
<td>a</td>
<td>78.6 ± 1.9</td>
<td>12.3 ± 1.0</td>
</tr>
<tr>
<td></td>
<td>NaFeEDTA L2</td>
<td>0.46 ± 0.09</td>
<td>a</td>
<td>81.0 ± 3.4</td>
<td>15.3 ± 1.0</td>
</tr>
</tbody>
</table>

Results are means of 3 measurements ± standard deviation; values in one column for the same sauce with different superscript letters are significantly different (p < 0.05). L1 and L2 are two levels of fortification, L1 = 8 mg of iron/100 g of sauce; L2 = 16 mg of iron/100 g of sauce.
Acknowledgements

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References

Traditional sub-African dish: leafy vegetable sauce + cereal paste “ tô”

Variations of Fe and Zn bioaccessibility:
- Improvement of iron bioaccessibility through fortification
- Effect of iron fortification on zinc bioaccessibility
- Fortificant influence
- Matrix effect
- Potential effect of fibers on iron and zinc bioaccessibility