Iron chemical speciation in brazilian fortified infant foods

Gabriel Silvério Filbido IFMT
Isabela Mendes Pacheco Narita IFMT
Ana Paula de Oliveira Pinheiro IFMT
Daphane da Cruz e Silva IFMT
Bruno Araujo Ferreira IFMT
Talissa de Oliveira Gonçalves IFMT
Edgar Nascimento IFMT
Ricardo Dalla Villa UFMT
Adriana Paiva de Oliveira IFMT
ABSTRACT

This work aimed to investigate the chemical speciation of iron in infant Brazilian fortified foods: lactea flour, infant cereal, powdered chocolate and powdered milk. For this purpose, two brands of each type of sample were collected from supermarkets in the Cuiabá city. The samples were subjected to dry decomposition, and the total Fe concentration was determined by flame atomic absorption spectrometry. The Fe$^{3+}$ concentration was determined by spectrophotometry using the thiocyanate method, while that of Fe$^{2+}$ was obtained by difference. The results showed higher concentrations of Fe$^{3+}$ in relation to Fe$^{2+}$ for the two brands lactea flour (2.1 ± 0.3 mg/100g Fe$^{3+}$ and 0.8 ± 0.0 mg/100g Fe$^{2+}$; 7.4 ± 1.1 mg/100g Fe$^{3+}$ and 4.6 ± 0.1 mg/100g Fe$^{2+}$), two brands powdered milk (3.4 ± 0.4 mg/100g Fe$^{3+}$ and 2.5 ± 0.1 mg/100g Fe$^{2+}$; 4.4 ± 0.4 mg/100g Fe$^{3+}$ and 4.0 ± 0.1 mg/100g Fe$^{2+}$) and one brand powdered chocolate (1.5 ± 0.3 mg/100g Fe$^{3+}$ and 0.9 ± 0.1 mg/100g for Fe$^{2+}$). This may denote the use of weak fortifying agents, insoluble substances and high concentrations of absorption-inhibiting substances. The results obtained indicate the use of fortifying agents of low bioaccessibility due to the higher concentrations of Fe$^{3+}$ present in the samples.

Keywords: Mineral, Bioavailability, Micronutrients, Iron Deficiency Anemia, Speciation.
INTRODUCTION

Anemia is defined by the World Health Organization (WHO) as an insufficient level of red blood cells to meet physiological needs. In the world, around 600 million children are affected by this condition, and lack of iron has been indicated as a contributing factor to iron deficiency anemia. The iron deficiency was estimated to affect four billion people worldwide, and over two billion people suffer from iron deficiency anemia, mainly in underdeveloped countries and low-income populations (BARBOSA et al., 2012; QUINTAES et al., 2017; WORLD HEALTH ORGANIZATION, 2011).

Iron deficiency anemia is one of the most serious public health problems in the world, and also represents one of the main nutritional deficiencies, due to its negative health effects. This deficiency can be caused by several factors, such as insufficient dietary iron, low absorption of iron in the diet, and increased need or loss of this mineral (BRAGA and VITALLE, 2010; WORLD HEALTH ORGANIZATION, 2006).

Children under 5 years are considered one of the most vulnerable groups, due to the greater iron needs in the stages of growth and development, characteristic of this age group. Many studies reported that iron deficiency anemia in children can cause cognitive and psychomotor development deficits, as well as increased tendency to infections. In Brazil, according to data from the National Demographic and Health Survey of Women and Children, the prevalence of iron deficiency anemia in children under 5 years was 20.9% (BRAGA and VITALLE, 2010).

One of the strategies to combat iron deficiency anemia and other nutritional deficiencies is to fortify food products. However, many manufacturers add fortifying agents with low bioaccessibility. The Brazilian legislation only establishes parameters for the total micronutrient contents of fortified foods. However, previous studies indicated that most mineral elements are not fully absorbed by the body, with the chemical form being the main factor affecting the bioavailability of a mineral (KHOUZAM et al., 2012; REIS and GONÇALVES, 2015).

In this context, chemical speciation can be an alternative analytical technique for evaluating the fortification of foods with minerals such as iron, which has two oxidation states: Fe$^{3+}$ (less bioaccessible) and Fe$^{2+}$ (more bioaccessible). The chemical speciation analysis of nutrients involves determining the concentration of the different chemical forms of a substance, whose total concentration in the matrix is given by the sum of the individual concentrations. In recent years, the chemical speciation of nutrients in foods has attracted great interest, because it allows understanding the behavior of the different chemical forms of a nutrient (KHOUZAM et al., 2012; NIEDZIELSKI et al., 2014; OLIVEIRA and NAOKUZA, 2015; REIS and GONÇALVES, 2015).
Thus, in order to improve iron fortification strategies to combat iron deficiency anemia, it is essential to characterize the chemical species used in the fortifying agents. From this perspective, the objective of this work was to determine the chemical speciation of iron by quantifying the concentrations of total Fe, Fe$^{3+}$, and Fe$^{2+}$ in Brazilian fortified infant foods, such as milk flour, infant cereals, powdered chocolate, and powdered milk.

**MATERIALS AND METHODS**

**Instrumentation**

An analytical balance with an accuracy of ± 0.0001 g (Shimadzu® model auy-220-unibloc, Kyoto, Japan) was used for weighing the samples and reagents. High-purity deionized water (resistivity 18.2 MΩ cm, Elga® model Purelab Option Q7, High Wycombe, United Kingdom) was used for the preparation of the standard solutions and samples.

The sample preparation procedure was carried out in a muffle furnace (Zezimaq® model 2000 F, Minas Gerais, Brazil) and a hot plate (Quimis® model Q313I21, São Paulo, Brazil). The concentration of Fe$^{3+}$ was determined using an ultraviolet-visible (UV-Vis) spectrophotometer (Shimadzu® model UV 1800, Kyoto, Japan). The total Fe concentration was measured by flame atomic absorption spectrometry (FAAS, Varian® SpectrAA model 220, Santa Clara, USA) fitted with hollow cathode lamps. Acetylene (99.9%, Linde Gas, São Paulo, Brazil) and compressed air were used as fuel and oxidant gases, respectively. Micropipettes (Kasvi, Germany) with adjustable volumes of 10–100 and 100–1000 μL were used for the preparation of the standard solutions and samples.

**Reagents**

Nitric acid (≥65%, Qhemis, São Paulo, Brazil) and hydrochloric acid (37%, Qhemis, São Paulo, Brazil) were used for the sample decomposition.

Fe$^{3+}$ quantification was carried out using ferrous ammonium sulfate (98.5%, Dinâmica Química Contemporânea, São Paulo, Brazil), potassium thiocyanate (98.5%, Synth, São Paulo, Brazil), and nitric acid (≥65%, Qhemis, São Paulo, Brazil). Working standard solutions of Fe were prepared by appropriate dilutions of 1000 mg L$^{-1}$ aqueous stock solutions (Specsol, São Paulo, Brazil).

A certified rice flour standard reference material (AR 2028, lot # 70501, Alpha Resources LLC, Stevensville, USA) was employed for the evaluation of the precision and accuracy of the total Fe determination method.
Samples

Chocolate milk, milk flour, milk powder, and infant cereal were selected as fortified infant foods. Corresponding samples were randomly collected from supermarkets of the Cuiabá city, Mato Grosso, Brazil. Two brands were selected for each food, for a total of eight evaluated samples (brands A to H).

All fortified infant foods were used within their expiration date and stored in a dry place after collection. Immediately before the analysis, the samples were homogenized and quartered (ADOLPHO LUTZ INSTITUTE, 2008).

Determination of total Fe, Fe$^{3+}$, and Fe$^{2+}$ concentrations

For the determination of total Fe and Fe$^{3+}$ concentrations, 2.0 g of the samples were initially heated in a muffle furnace at 550 °C for 4 h. Then, the ashes were submitted to wet decomposition with 2.0 mL of deionized water, 1.0 mL of 37% (w:v) HCl, and 2.0 mL of 65% (v:v) HNO$_3$ in a heating plate at a temperature of 120 °C, to digest the samples for about 30 min. After cooling, the digests were filtered, transferred quantitatively into a 50-mL volumetric flask, and diluted to the calibration mark with deionized water (ADOLPHO LUTZ INSTITUTE, 2008).

The Fe$^{3+}$ concentration was determined by UV-Vis spectrophotometry using the thiocyanate method, which involved complexation of Fe$^{3+}$ ions to form [Fe(SCN)$_6$]$_{3-}$ species, absorbing at the wavelength of 450 nm (MENDHAM et al., 2000). External calibration was carried out with the following Fe$^{3+}$ concentrations: 0.0, 0.72, 1.43, 2.15, 2.87, 4.30, and 5.02 mg L$^{-1}$. All determinations were made in triplicate ($n = 3$), accompanied by an analytical blank.

The total Fe concentrations were determined by FAAS. The aspiration rate of the working standard solutions or samples was adjusted to 2.3 ± 0.0 mL min$^{-1}$ and the measurements were carried out according to the manufacturer’s recommendations. External calibration was carried out using aqueous solutions prepared from a stock standard solution in 1.0% HNO$_3$, containing the (total) Fe analyte at the following concentrations: 0.0, 0.05, 0.1, 0.2, 0.4, 0.8, 2.0, 4.0, and 6.0 mg L$^{-1}$. All determinations were made in triplicate ($n = 3$), accompanied by an analytical blank (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, 2012).

The instrumental limit of detection (LOD) and limit of quantification (LOQ) values were determined according to Currie (1999). The linearity was evaluated using criteria such as the correlation coefficient ($r$).

The accuracy and precision of the method for total Fe determination was evaluated by the quantification of a certified reference material (AR 2028 rice flour). In the case of Fe$^{3+}$, we used addition and recovery tests performed for one fortification level in the samples. All tests were
made in triplicate \((n = 3)\), accompanied by an analytical blank (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, 2002).

The concentration of \(\text{Fe}^{2+}\) was calculated as the difference between the total \(\text{Fe}\) and \(\text{Fe}^{3+}\) concentrations.

**Statistical analysis**

The total \(\text{Fe}\), \(\text{Fe}^{3+}\), and \(\text{Fe}^{2+}\) concentrations measured for the fortified infant food samples were subjected to normality (Shapiro-Wilk) and Student’s tests to compare the mean values obtained for the different brands of each product (significance level \(p \leq 0.01\)), using the R software, version 3.5.1. The experiments were conducted according to a completely randomized design with three replications.

**RESULTS AND DISCUSSION**

The analytical curve for \(\text{Fe}^{3+}\) quantification presented a linear correlation coefficient of 0.98, along with instrumental detection and quantification limits (LDI and LQI, respectively) of 1.28 and 3.87 mg \(\text{Fe}^{3+}/100\ g\), respectively. In the case of the total \(\text{Fe}\) concentration, the linear correlation coefficient obtained by the analytical curve was 0.99 and the LDI and LQI values were 0.14 and 0.34 mg total \(\text{Fe}/100\ g\), respectively.

In order to assess the precision and accuracy of the method for the quantification of total iron, we used a certified reference material with concentration of \(1–10\ \text{mg/\mu g}\). For this concentration range, the Association of Official Analytical Chemists recommends that the average allowable recovery should vary between 80 and 110% (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, 2016). The value obtained from the recovery of the present mineral was \(84.53\% \pm 0.84\) (mean \(\pm\) standard deviation), thus within the recommended limits.

The \(\text{Fe}^{3+}\) recovery percentages ranged from 100.6 to 107.6%, with standard deviations of less than 3.0 (Table 1). The AOAC establishes a recovery range for the used fortification level (28 mg/kg) from 90 to 107% and a standard deviation of 5.3 (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, 2016).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Brand</th>
<th>(\text{Fe}^{3+}) recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant cereal</td>
<td>A</td>
<td>107.6 ± 2.4</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>103.5 ± 3.0</td>
</tr>
<tr>
<td>Milk flour</td>
<td>C</td>
<td>100.6 ± 1.6</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>103.6 ± 0.3</td>
</tr>
<tr>
<td>Powdered milk</td>
<td>E</td>
<td>102.8 ± 3.3</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>105.9 ± 0.2</td>
</tr>
</tbody>
</table>
Total Fe quantification

Codex Alimentarius and ANVISA classify foods with micronutrients in two classes: added foods that include the expression “source” in the label, and fortified foods that are described as “rich” or “high content” on the label (BRAZILIAN HEALTH REGULATORY AGENCY, 1998; CODEX ALIMENTARIUS, 1997). For a solid food to be considered as mineral- and/or vitamin-added, it must provide a maximum of 15% of the reference recommended daily intake (IDR) in 100 g of the final product, while fortified/enriched foods need to contain at least 30%.

Table 2. shows the total Fe concentrations measured in the samples, as well as the total Fe content indicated on the label and the percentage of fortifying infant foods established by the Food and Drug Administration (FDA) and the Brazilian Health Surveillance Agency (ANVISA) (BRAZILIAN HEALTH REGULATORY AGENCY, 1998; CODEX ALIMENTARIUS, 1997).

According to Table 2, all evaluated infant foods can be considered enriched, as they present a percentage of fortification greater than 30% of the reference IDR and recommended daily intake (RDA) values (BRAZILIAN HEALTH REGULATORY AGENCY, 1998; CODEX ALIMENTARIUS, 1997).

Table 2. Results (mean ± standard deviation) of total Fe concentration in Brazilian fortified infant foods, label values, and percentage of fortification relative to FDA and ANVISA recommendations.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Brand</th>
<th>Total Fe (mg/100 g)</th>
<th>Fortification according to FDA* (%)</th>
<th>Fortification according to ANVISA** (%)</th>
<th>Label (mg/100 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant cereal</td>
<td>A</td>
<td>8.6 ± 0.2*</td>
<td>123.6</td>
<td>144.2</td>
<td>30.45</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>8.5 ± 0.3*</td>
<td>121.6</td>
<td>141.8</td>
<td>31.43</td>
</tr>
<tr>
<td>Milk flour</td>
<td>C</td>
<td>3.0 ± 0.3*</td>
<td>43.3</td>
<td>50.5</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>12.8 ± 0.2*</td>
<td>183.1</td>
<td>213.7</td>
<td>9.0</td>
</tr>
<tr>
<td>Powdered milk</td>
<td>E</td>
<td>5.9 ± 0.2*</td>
<td>84.9</td>
<td>99.0</td>
<td>16.15</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>8.3 ± 0.2*</td>
<td>118.1</td>
<td>137.8</td>
<td>21.2</td>
</tr>
<tr>
<td>Powdered chocolate</td>
<td>G</td>
<td>5.4 ± 0.0*</td>
<td>77.9</td>
<td>90.8</td>
<td>10.5</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>2.1 ± 0.0*</td>
<td>30.6</td>
<td>35.7</td>
<td>Not shown</td>
</tr>
</tbody>
</table>

* Statistically significant difference at the 1% confidence level.
** Percentage of iron fortification in food, relative to the recommended daily intake (RDA) for children aged 1 to 12 years established by the ANVISA (minimum 6 mg/day) (BRAZILIAN HEALTH REGULATORY AGENCY, 1998; CODEX ALIMENTARIUS, 1997).
total Fe content in agreement with that indicated in the nutrition label; this may be indicative of high concentrations of phytates, which contribute to reduce the total iron concentration.

Cereal-based products, such as wheat and corn, contain large amounts of phytates. These substances have the ability to form insoluble complexes with iron, hindering its quantification and even decreasing its bioaccessibility. Previous studies indicate that the absorption of iron from cereal derivatives can be improved by treatment using the phytase enzyme or with the addition of ascorbic acid (COZZOLINO, 2012).

Thus, phytates can form insoluble complexes with iron species and interfere with the quantification of Fe$^{2+}$ and Fe$^{3+}$. To reduce the content of these antinutrients and improve iron solubility, phytase treatment of cereal-based foods may be an effective strategy, since this enzyme hydrolyzes the phytates naturally present in these products (THEODOROPOULOS et al., 2018).

For milk flours, statistically significant differences (at the 1% level) in the total Fe content were found between the two brands evaluated in the experiments. The D brand showed a total Fe content above that indicated in the label, while the value measured for the C brand was below that of the label. The difference between the two brands may be related to the type of powdered milk used in the milk flour production.

Turning to powdered milk, the two brands exhibited statistically significant (at the 1% level) differences in the levels of total Fe, as shown in Table 2. In addition, the obtained contents were below those indicated in the nutrition label, which can be attributed to the presence of a high concentration of calcium.

It is worth noting that the calcium naturally present in milk can mask metal ions, such as Fe, making it difficult to quantify their chemical forms. In addition, iron fortification of milk can impair the absorption of this mineral, due to the concomitant presence of calcium in this food product, because both minerals compete for the same absorption sites in the small intestine (TOXQUI et al., 2013; WORLD HEALTH ORGANIZATION, 2006).

A statistically significant difference (at the 1% level) was also found for the total Fe concentration in the two brands of powdered chocolate milk (Table 2). In addition, the H brand can be classified as an iron-rich food, even if its label does not report the total Fe value. The G brand showed total Fe values below those indicated in the nutrition label.

It is also worth mentioning that chocolate milk products are usually consumed with milk, so their fortification can also be hindered by the calcium naturally present in the product. Some studies indicate that the degree of inhibition of Fe absorption by Ca is related to the dose, as the consumption of high calcium amounts can drastically decrease the bioaccessibility of Fe (COZZOLINO, 2012).
**Chemical speciation of iron**

Iron can be present in two chemical forms in food products: heme iron (Fe$^{2+}$, a more bioaccessible species), and non-heme iron (Fe$^{3+}$, less bioaccessible). The quantification of these two species is extremely important, because the human body absorbs less Fe$^{3+}$; this is because the latter needs to be reduced to Fe$^{2+}$ through the enzyme Dcytb and then internalized to the duodenal enterocytes (COZZOLINO, 2012).

Table 3 presents the results (mean and standard deviation) of the total Fe, Fe$^{3+}$, and Fe$^{2+}$ concentrations measured for the infant cereals, milk flours, powdered chocolate, and powdered milk samples.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Brand</th>
<th>Total Fe (mg/100 g)</th>
<th>Fe$^{2+}$ (mg/100 g)</th>
<th>Fe$^{3+}$ (mg/100 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant cereal</td>
<td>A</td>
<td>8.6 ± 0.2$^a$</td>
<td>4.9 ± 0.1$^a$</td>
<td>3.9 ± 0.3$^a$</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>8.5 ± 0.3$^a$</td>
<td>5.1 ± 0.1$^a$</td>
<td>3.2 ± 0.2$^a$</td>
</tr>
<tr>
<td>Milk flour</td>
<td>C</td>
<td>3.0 ± 0.3$^b$</td>
<td>0.8 ± 0.0$^b$</td>
<td>2.1 ± 0.3$^b$</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>12.8 ± 0.2$^a$</td>
<td>4.6 ± 0.1$^a$</td>
<td>7.4 ± 1.1$^a$</td>
</tr>
<tr>
<td>Powdered milk</td>
<td>E</td>
<td>5.9 ± 0.2$^a$</td>
<td>2.5 ± 0.1$^a$</td>
<td>3.4 ± 0.4$^a$</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>8.3 ± 0.2$^a$</td>
<td>4.0 ± 0.1$^a$</td>
<td>4.4 ± 0.4$^a$</td>
</tr>
<tr>
<td>Powdered chocolate</td>
<td>G</td>
<td>5.4 ± 0.0$^b$</td>
<td>3.2 ± 0.0$^b$</td>
<td>2.4 ± 0.3$^b$</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>2.1 ± 0.0$^b$</td>
<td>0.9 ± 0.1$^b$</td>
<td>1.5 ± 0.3$^b$</td>
</tr>
</tbody>
</table>

$^a, b$ Statistically significant difference at the 1% confidence level.

Table 3 shows the results of the Fe$^{2+}$ and Fe$^{3+}$ quantification in the fortified infant foods evaluated in this study. In the case of infant cereals, a higher content of Fe$^{2+}$ than Fe$^{3+}$ was found for both brands. This indicates that the fortifying agent added in these products may be more soluble in water, and therefore possess a higher absorption index. Ferrous sulfate is commonly used for the enrichment of cereals; however, this compound can cause undesirable changes in the final product, such as rancidity, and its encapsulated form is thus recommended for fortification of food products (WORLD HEALTH ORGANIZATION, 2006).

Wortley et al., (2005) compared the bioavailability of 14 types of iron-fortifying agents in cereals, based on an *in vitro* model using Caco-2 cells. The bioavailable content of the fortified cereals was compared to a control cereal (with no fortification). The results showed that electrolytic iron exhibited the lowest bioavailability (52%), while Na$_2$FeEDTA achieved a 291% higher iron bioavailability relative to that of the control cereal.

Due to the high iron deficiency anemia index in Brazil in the last decades, the ANVISA resolution no.150 has established that the fortification of wheat and corn flour should be carried out only with soluble fortifying agents of high absorption, such as ferrous sulfate, ferrous fumarate, and their encapsulated forms, prohibiting fortification with electrolytic iron (insoluble in water) (BRAZILIAN HEALTH REGULATORY AGENCY, 2017).
The two examined brands of milk flour exhibited different levels of Fe\(^{2+}\) and Fe\(^{3+}\) (Table 3), suggesting that a poorly water-soluble or water-insoluble iron-fortifying agent was used in these products.

In many countries, farinaceous products are still fortified with elemental iron or low-absorption compounds, due to the lower cost and the non-sensorial degradation of the food matrix. To combat the high rates of iron deficiency anemia in the world, current legislation needs to be modified, not only in terms of the added amount of micronutrients, but also of the type and quality of fortifying agent used in the food products (HURRELL et al., 2010).

Powdered milk is one of the most popular food products for children. As shown in Table 3, a higher Fe\(^{3+}\) concentration was found for the two brands evaluated in this work. The high content of this chemical form of Fe may be related to the addition of ferrous fumarate, a fortifying agent that is poorly soluble in water; however, ferrous sulfate is the recommended fortifying agent, due to its higher bioaccessibility. Other compounds such as ferric ammonium citrate and ferric pyrophosphate are also used for liquid milk, because they do not cause undesirable changes in this product (WORLD HEALTH ORGANIZATION, 2006).

Walczyk et al. (2013) compared the bioavailability of ferrous ammonium phosphate, ferric pyrophosphate, and ferrous sulfate in powdered milk. The results showed that ferrous sulfate was the compound with the highest absorption (10.4%), followed by ferrous ammonium phosphate (7.4%), and ferric pyrophosphate (3.3%). Even when water-soluble Fe fortifiers are employed, it is recommended to add ascorbic acid to powdered milk, because it is beneficial for iron absorption.

In the case of powdered chocolate, Table 3 shows that the G brand exhibited higher levels of Fe\(^{2+}\) and Fe\(^{3+}\) compared to those of the H brand. Moreover, the H brand also shows a high content of the less bioaccessible Fe\(^{3+}\) species.

For the fortification of these products, it is recommended to use ferrous sulfate in its encapsulated form. However, it is known that cocoa derivatives are rich in phenolic substances; together with the addition of water-soluble fortifying agents, this can cause changes in the color of powdered chocolate, which is not desirable in an industrial context (WORLD HEALTH ORGANIZATION, 2006).

Many industries use ferric pyrophosphate to enrich powdered chocolate, even though this compound is insoluble in water and has low absorption. Some studies suggest that the bioaccessibility of ferric pyrophosphate and other iron-fortifying agents can be enhanced by combining them with inulin-type fructans and oligosaccharides, as these carbohydrates can be fermented in the intestine and form acidic substances, thus reducing the intestinal pH and improving mineral absorption (LOBO et al., 2011).
CONCLUSIONS

All infant foods evaluated in this study could be classified as fortified with iron, as they showed total iron values higher than 30% of the daily reference intake for children in 100 g of product. However, for all samples (with the exception of the D brand milk flour), the total iron values obtained in this study were lower than those indicated in the nutrition label.

The results obtained from the chemical speciation analysis indicated that the two brands of milk flour, powdered milk, and powdered chocolate brand H presented higher concentrations of Fe$^{3+}$ than Fe$^{2+}$. Thus, the obtained values suggest that these foods may have been enriched with fortifying agents of lower bioaccessibility and/or by a high concentration of absorption inhibitors, such as phytates, calcium, and fibers.

In summary, studies on the chemical speciation of iron in foods can contribute to improve our understanding of the different oxidation states of minerals present in a given product, as well as to estimate their bioaccessibility by the body. The present results highlight the need to create legislation concerning the fortification of infant foods, in order to decrease the occurrence of nutritional deficiencies in the world.

Acknowledgments

The authors thank the IFMT for supporting this research (Edict 04/2018 PROPES/IFMT for support and promotion to postgraduate and Edict 32/2019 PROPES/IFMT for publication of scientific articles), the Coordination for the Improvement of Higher Education Personnel (CAPES) for granting a scholarship to G.S.F., and the Análise de Contaminantes Inorgânicos Laboratory of the Chemistry Department of UFMT.

■ REFERÊNCIAS


