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Effect of different iron compounds on rheological and technological parameters as well as bioaccessibility of minerals in whole wheat bread

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ABSTRACT

This study aimed at investigating the effect of iron compounds used in whole wheat flour (WWF) fortification, both on rheological properties of the dough and on bread technological quality. Furthermore, bioaccessibility of iron (Fe), zinc (Zn) and calcium (Ca) in the final breads was determined. Rheological properties (mainly dough development time, stability, mixing tolerance index, resistance to extension and ratio number) of the dough and the technological quality of bread (mainly oven spring and cut opening) were altered. However, producing roll breads fortified with different iron compounds was still possible. NaFeEDTA (ferric sodium ethylene diamine tetra acetic acid) proved to be the most effective iron compound in the fortification of WWF, since it presented the highest levels of solubility (44.80%) and dialysability (46.14%), followed by microencapsulated ferrous fumarate (FFm). On the other hand, the microencapsulated ferrous sulfate (FSm) and reduced iron presented the lowest solubility (5.40 and 18.30%, respectively) and dialysability (33.12 and 31.79%, respectively). Zn dialysis was positively influenced by NaFeEDTA, FSm, and ferrous fumarate. As for Ca, dialysis was positively influenced by FSm and negatively influenced by FFm. The data indicated that there is a competitive interaction for the absorption of these minerals in whole wheat roll breads, but all studied minerals can be considered bioaccessible.

1. Introduction

In Brazil, roll bread is the most consumed type of bread, and the incorporation of bran, with or without wheat germ, has been generally accepted by the population (Brasil, 2005), because of the high fiber content and presence of most of the nutrients, such as: vitamins, amino acids, antioxidants, minerals (iron, zinc, calcium, magnesium, phosphorus, potassium) (Buri, von Reding, & Gavin, 2004).

Although wheat flour contains iron (Fe), zinc (Zn), and calcium (Ca), it has been used as a carrier in fortification programs in order to improve nutrient absorption, particularly in what concerns Fe, since the lack of this mineral in the body can cause serious health consequences (Brasil, 2002). Iron deficiency anemia is currently considered a public health problem which occurs in about 25% of the population worldwide (WHO, 2006). Moreover, Zn and Ca are also considered important for the proper functioning of the human body (Casé, Deliza, & Rosenthal, 2005; Pereira & Hessel, 2009).

The fortification of wheat and corn flours with iron is carried out in many countries. Actually, in Brazil, it is performed since 2002 (Brasil, 2002). The Brazilian Legislation allows the addition of iron compounds (4.2 mg/100 g), such as: dehydrated ferrous sulfate (dried) (FS), ferrous fumarate (FF), reduced iron (RI), electrolytic iron, ferric sodium ethylene diamine tetra acetic acid (NaFeEDTA), ferrous glycinate chelate, and other bioavailable compounds, that are not inferior in bioavailability to those permitted (Brasil, 2002).

Some studies associate the use of different iron compounds with possible alterations that may occur in food, such as sensory and technological properties (dough rheology and final product quality), differences in bioavailability, and the cost of each iron form. These factors must be taken into consideration in the Fe fortification process (Akhtar, Anjum, & Anjum, 2011; WHO, 2006).

The rheological properties of flour dough can provide information on the behavior of dough manipulation during processing. They also serve as a quality indicator for the final product. Alterations in these parameters are not desirable (Sollars & Rubenthaler, 1975).

Different iron compounds used for fortification may affect the mineral bioavailability and bioaccessibility in different ways. It is noteworthy that iron compounds such as: FS, FF, NaFeEDTA, and FSm are indicated for cereals fortification, since they are more likely to be absorbed by the body (Akhtar, Anjum, Rehman, & Sheikh, 2009; Hurrell et al., 2010). Furthermore, the microencapsulated iron

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compound has the advantage of protecting the food from undesirable organoleptic alterations, besides preventing oxidation (Cocato, Ré, Trindade Neto, Chiebao, & Colli, 2007). There are studies that suggest replacing ferrous sulfate by microencapsulated ferrous sulfate, as a fortification alternative, considering its advantages (Cocato et al., 2007; Gotelli et al., 1996; Lysionek et al., 2001).

Several authors used in vitro methods to study the availability of iron and other minerals in order to understand which compounds are the most effective in the fortification process (Benito & Miller, 1998; Cámara, Amaro, Barberá, & Clemente, 2005; Kapsokefalou, Alexandropoulou, Komaitis, & Politis, 2005; Miller, Schricker, Rasmussen, & Van Campen, 1981; Perales, Barbera, Lagarda, & Farre, 2006). Moreover, there are studies that associate low mineral absorption with the presence of antinutritional factors, such as phytates (Schons, Ries, Battestin, & Macedo, 2011), which are present in plant seeds and grains and in high amounts in wheat bran. Phytate [myo-inositol (1,2,3,4,5,6) hexakisphosphate] is the stored form of phosphate in plant seeds and the most abundant inositol phosphate in nature. In isolated form myo-inositol (5, 6) being the most important for complexing minerals in foods (Greiner & Konietzny, 2006). Furthermore, its ability of chelating multivalent cations (De Carli, Rosso, Schnitzler, & Carneiro, 2006), such as $Fe^{2+/3+}$, Cu^{2+}, Zn^{2+} and Ca^{2+} (Ries, 2010), which are poorly soluble, reduces the bioaccessibility of the bound cations (Carbonaro, Grant, Mattera, Aguzzi, & Pusztai, 2001).

To the best of our knowledge, this is the first report which describes the effect of different iron compounds used to fortify whole wheat flour on dough rheological characteristics, quality properties of whole wheat roll bread and bioaccessibility of Fe, Zn, and Ca in the final bread. In addition, myo-inositol phosphate esters (phytates) were quantified in the final breads.

2. Material and methods

2.1. Preparation of whole wheat roll breads (WWRB)

To obtain whole wheat flour (100 kg), 6% of wheat bran were incorporated into 94% of refined wheat flour (Moinho Guaçu Mirim, Brazil). The whole wheat flour (WWF) (control) was characterized for its composition. It presented moisture, proteins, lipids, and ash contents of 13.22 ± 0.11, 12.95 ± 0.42, 1.29 ± 0.01, 0.80 ± 0.02 g/100 g, respectively (methods 44-15.02, 46-13.01, 30-25.01, and 08-01.01, AACC (2010), respectively). The total dietary fiber content was 6.91 ± 0.31 g/100 g (method 985.29, AOAC (2000)).

The iron compounds used in the fortification were: monohydrated ferrous sulfate (FS), ferrous fumarate (FF), reduced iron (Nutrafine, RS, Brazil) (RI), ferric sodium ethylene diamine tetra acetic acid (NaFeEDTA) (Vogler Ingredients, SP, Brazil), microencapsulated ferrous sulfate (FSm), and microencapsulated ferrous fumarate (FFm) (Functional Mikron, Valinhos, Brazil). The quantification of iron content in WWF was performed before and after the fortification process, according to Rebellato, Pacheco, Prado, and Lima Pallone (2015). The iron concentration found in WWF was 1.38 ± 0.06 mg/100 g. In the fortification process, each sample was homogenized using a V-blender (Tecnal Piracicaba, Brazil) for 30 min, in 5.0 kg portions. After adding the different iron compounds to WWF, the obtained Fe concentrations ranged from 4.80 to 6.29 mg/100 g.

The whole wheat roll breads (WWRB) were elaborated using the Modified Straight Dough Method. The dry ingredients (100% whole wheat flour, 1.5% instant dry yeast, 1.8% salt, 2.5% bread improver) and water (614.80 ± 28.40 mL) were mixed in a HAE 10 mixer (Hyppolito, Ferraz de Vasconcellos, Brazil), at slow speed for 4 min, then at high speed until full development of the gluten network. The dough was divided into 65 ± 1 g portions, rounded and left to rest for 15 min. Then, they were molded in a HM2 Hp 0.5 molder (Hyppolito, Ferraz de Vasconcellos, Brazil) and proofed in a 20B proofing chamber (Super Freezer, Poços de Caldas, Brazil) for 60–70 min at 27–30 °C with a relative humidity of 85–90%. After fermentation, a cut opening was made on the surface of the dough pieces, and then the samples were baked in a HF 4B oven (Haas, Curitiba, Brazil), with top and bottom (hearth) temperatures of 170 °C and 180 °C, respectively, for 16 ± 3 min. After cooling for ±30 min, the technological quality of breads was determined in one portion of the samples. Another portion (10 breads) was stored in the freezer (−20 °C) for mineral content (Fe, Zn, and Ca) analysis and quantification of *myo*-inositol phosphate esters. We used solubility and dialysis assays to estimate their bioaccessibility.

2.2. Rheological characterization

The same samples were subjected to rheological analysis. In detail, water absorption (WA), arrival time (AT), dough development time (DDT), stability (S), and mixing tolerance index (MTI) were evaluated using method 54-21.01 of the AACC (2010) and the Brabender Farinograph (Duisburg, Germany), model 827,505. To evaluate the extensographic properties, resistance to extension (R), maximum resistance (Rm), extensibility (E) and ratio number (D = R/E) were determined using the Brabender Extensograph (Duisburg, Germany), model 860,703, and method 54-10.01 of the AACC (2010).

2.3. Characterization of roll bread quality

The following parameters were determined in the final breads: specific volume (SV), using method 10-05.01 of the AACC (2010); shape, measuring height and width of the rolls according to Bodroza-Solarov, Filipcev, Kevresan, Mandic, and Simurina (2008); oven spring according to Shittu, Dixon, Awonorin, Sanni, and Maziya-Dixon (2008); cut opening and cut height according to Almeida and Chang (2012). All measurements were performed in four replicates.

2.4. Determination of myo-inositol phosphate esters

Myo-Inositol phosphate esters in the final breads were extracted according to Sandberg, Carlsson, and Svanberg (1989) and quantified using method 986.11 of the AOAC (2006).

2.5. Quantification of Fe, Zn, and Ca

The minerals were quantified using Flame Atomic Absorption Spectrometry, according to Rebellato et al. (2015). For Ca determination, a lanthanum oxide solution was added to obtain a final concentration of 0.5% in order to eliminate the possible interferences. The method used for the Zn and Ca quantification was validated based on parameters of precision, recovery, sensitivity, linearity, and limits of detection and quantification. The method was validated according to the analytical method validation guidelines.

The accuracy parameter set as the mean value of the variation coefficient, was ±10%. The recovery was performed by adding standard (Ca and Zn) to the control sample, at levels of 50 and 100%. Recovery percentages close to 100% were considered satisfactory. The sensitivity was expressed by the slope of the linear regression equation. The limits of detection and quantification were calculated based on the calibration curve and both were expressed in mg/100 g of bread.

2.6. Solubility and dialysis assay

The solubility assay was carried out according to Cámara et al. (2005), with modifications described by Rebellato et al. (2015). The volume of enzyme solution used in the enteral step was adjusted to 6.0 mL (0.4 g of porcine pancreatin, P-7545 and 2.5 g of bovine and sheep bile, B-8631, Sigma Chemical Co., St. Louis, USA, in 100 mL of $NaHCO_3$ 0.1 mol/L).

The dialysis assay was performed according to Perales et al. (2006), with modifications following Rebellato et al. (2015). In the enteral step,