Release of Iron into Foods Cooked in an Iron Pot: Effect of pH, Salt, and Organic Acids

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ABSTRACT: Amounts of iron released from iron pots vary from meal to meal. The effects of salt, pH, and organic acids as iron chelators were studied. Maize (corn) porridges were prepared in a cast iron pot from maize flour and 12 aqueous solutions with different pH (3.7 or 7.2), salt contents (0% or 0.5% NaCl), and organic acids (1% lactate, 1% citrate, or none). Salt had no effect, but acidic pH or organic acids (citrate > lactate) significantly increased iron amount, from 1.7 mg to 26.8 mg Fe per 100 g. The amounts released could be important in the treatment and prevention of iron deficiency.

Keywords: iron deficiency, iron pots, fermented porridge, organic acids, chelators

Introduction

IRON DEFICIENCY IS THE MOST PREVALENT NUTRIENT DEFICIENCY in the world, affecting about 3.5 billion people (UNICEF/UNU/WHO/MI 1999), mainly young children and women of reproductive age. Iron deficiency anemia is a major public health problem in many developing countries affecting about 150 million people. Iron supplementation with tablets is not successful as compliance is low due to gastrointestinal discomfort. Furthermore, tablet distribution is not sustainable. There is therefore an urgent need for alternatives.

Several studies have shown that iron is released to foods cooked in iron pots (Brittin and Nossaman 1986; De-Yu and others 1990; Cheng and Brittin 1991; Adish and others 1999). Cooking in iron pots has therefore been suggested as a way to increase the iron status in deficient populations. De-Yu and others (1990) estimated the increase in daily iron intake by the use of iron pots to 14.5 mg for adults and 7.4 mg for children, based on an average consumption of 1000 mL water, 500 g rice, 200 g meat and eggs, and 250 g of vegetables each day for an adult, and one-half of these amounts for a child. Iron released from iron cookware is bioavailable; this has been shown both *in vitro* and *in vivo*. Using an in vitro dialysis assay Adish and others (1999) showed that the amount of available iron increased in a meat and vegetable meal but not in a legume meal when cooked in an iron pot. Five to 8% of the iron was available in the meat and vegetable meals, which is at the same level as the availability of nonheme iron in food. In 2 intervention trials including 4- to 12-mo-old preterm infants in Brazil (Borigato and Martinez 1998) and 2- to 5-y-old children in Ethiopia (Adish and others 1999), the families were randomized to use an iron pot or a noniron pot for preparing food for the child. After 8 or 12 mo, respectively, the children in the groups using iron pots had significantly less anemia.

The effect of different food constituents on the amount of iron liberated from iron pots during cooking is largely unknown, except for an effect of pH and moisture content of the raw food (Brittin and Nossaman 1986). Reported increases ranged from 1.5 to 2 times in Ethiopian food (Adish and others 1999), and 2 to 5 times in Chinese food (De-Yu and others 1990), to 10 to 24 times in applesauce and spaghetti sauce (Cheng and Brittin 1991), and 4 to 12 times in curry meals (Fairweather-Tait and others 1995). The different increases in iron content are caused partly by the use of different cookware and different cooking procedures; however, these factors only account for minor differences and repeated use of cookware has little or no effect (Cheng and Brittin 1991). The composition of the cooked food is probably of major importance. Generally, release of iron from cooking pots is enhanced by cooking foods of low pH and high moisture content and by long cooking times (Brittin and Nossaman 1986). The effect of specific food constituents has not been studied systematically, but it is clear from the varying amounts found in earlier studies that food composition is important for the amount of iron liberated to the food during cooking.

We have undertaken a systematic study to establish the effect of salt, pH, and iron-binding organic acids on the ability of foods to dissolve iron from a cooking pot, using maize (corn) porridge as a neutral medium.

Materials and Methods

Chemicals

HNO_3 (65% suprapur), HCl (37% pro analysis), and H_2O_2 (30% suprapur) were from Merck (Darmstadt, Germany). Sodium DL-lactate (60 % syrup) was from Sigma (Sigma Chemical Co., St. Louis, Mo., U.S.A.). Citric acid, iron standard (Ttrisol) and all other chemicals (analytical grade) were from Merck.

Maize (corn) flour (finely ground, imported by Unifood Import A/S, Brøndby, Denmark) was purchased at a local store. All glassware was rinsed with acid to minimize contamination with iron.

Sample preparation

Maize flour (35.00 g) was suspended in 250.0 mL buffer in a cast iron cooking pot (Bestduty, Besaana/du Plessis Foundaries, Pretoria, South Africa) and adjusted to pH = 3.7 or 7.2. Buffered solutions were used of every combination of the following factors: pH = 3.7 (50 mM sodium acetate) or 7.2 (50 mM tris); salt (0% or 0.50% sodium chloride); and chelating compound (1.0% sodium lactate, 1.0% sodium citrate, or none). The porridge was cooked on a gas-cooking device for 2.5 min after the onset of boiling, and left covered with the lid for another 2.5 min. After thorough stirring with a plastic spoon, samples of 30 g were frozen in glass containers. The samples were freeze-dried using an Edwards Modulyo 4K freeze dryer (Edwards High Vacuum International, Crawly, West Sussex, U.K.) and kept in plastic bags until further analysis. Samples were cooked in duplicate, and the 24 samples were cooked and analyzed in random order.

Iron analysis

The total iron content of the samples was determined using atomic absorption spectrometry (AAS) based on the method of the Danish Standardization Board (Danish Standardization 1982a, 1982b). Samples (0.500 g) of freeze-dried maize porridge were weighed into composite vessels (CEM MDS 81D; CEM Corp., Matthews, N.C., U.S.A.) and 7.00 mL concentrated nitric acid was added. The samples were digested in a dedicated microwave oven (MES-1000 Extraction System; CEM Corp.). After digestion, 5 drops of H_2O_2 (30%) were added to each vessel, and the vessels were left at room temperature overnight. The contents of the vessels were quantitatively transferred to volumetric flasks, and water was added to a final volume of 10.00 mL. The iron content was determined by AAS (Spectra AA-200; Varian, Australia) using a standard curve based on an iron standard, and the AAS method was controlled with a standard certified reference material (Standard Reference Material 1548a "Typical Diet;" National Inst. of Standards and Technology, Gaithersburg, Md., U.S.A.).

Statistical analysis

Analysis of variance was performed using SAS (SAS Inst. Inc., Cary, N.C., U.S.A.).

Results and Discussion

THE IRON CONTENTS IN PORRIDGE SAMPLES OF DIFFERENT PH, AND with different contents of salt and organic acids, are shown in Figure 1. The effect of pH was strongly significant ($p < 0.001$), with an increase in iron content of 2 to 9 times when the pH was lowered from 7.2 to 3.7. The effect of chelating compounds was also highly significant ($p < 0.001$), with the complex-forming compounds enhancing the iron uptake of the porridge, and with more iron dissolved in the samples containing citrate than in the samples containing lactate. No significant effect was found of salt. With a dry matter content of 13%, the amounts of iron determined in the study corresponded to 1.7 mg Fe/100 g porridge in the samples of lowest iron content (pH = 7.2, no chelating compound) as compared to 26.8 mg Fe/100 g porridge in the samples of highest iron content (pH = 3.7, citrate).

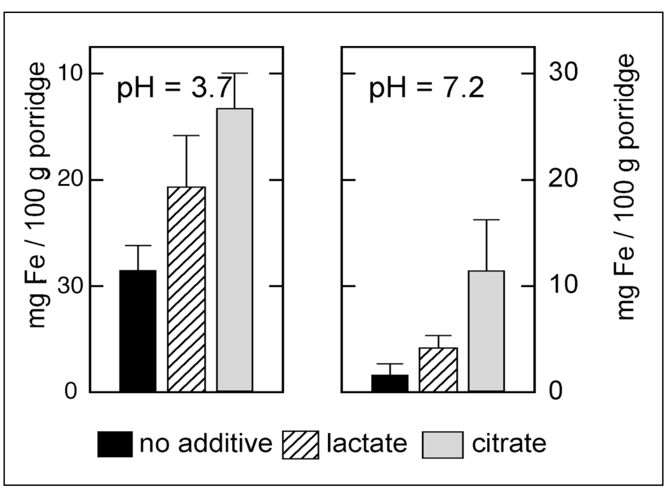

Figure 1—Iron contents of maize porridge of different compositions (n = 4). Data with and without salt have been pooled.

We thus found a strong effect of pH and organic acids on iron release, while there was no effect of salt. We used maize porridge as a neutral matrix, which is a traditional staple food in many countries where iron deficiency is frequent. Fermented maize porridge is used traditionally in many African societies, and the reason we chose a pH of 3.7 was to simulate the pH in a traditional maize porridge. The levels of lactic acid (1.0%) and acetic acid (0.1%) were used as they are close to the levels found in a traditional fermented maize porridge; the pH is likely to have a pronounced effect, because iron is dissolved by H+ as described by the following equations:

$$Fe + 2\,H^+ \rightarrow Fe^{2+} + H_2$$
$$Fe^{2+} + n\,L^- \leftrightarrow FeL_n^{(n-2)-}$$

where L^- is a chelating agent such as a hydroxycarboxylate. Compounds which form complexes with iron could also be expected to increase the release of iron to the food, possibly because they could adhere to the iron surface and facilitate dissolution of iron, rather than because formation of such complexes would lower the amount of free iron in the food and thereby enhance further release of iron. The effect of chelators is thus rather a kinetic than a thermodynamic effect. The equilibrium concentration will in principle vary with pH according to the Nernstian equation. However, it is unlikely that an equilibrium will be established because of the relatively short cooking time. Citrate is in general a better chelator than lactate due to the presence of 3 carboxylic groups compared to one. Citrate is also efficient as a chelator at lower pH due to the low value of pK_{a1} (Hamm and others 1954; Glebov and others 1990). The different abilities of the 2 organic acids to facilitate release of iron from the pot indicates that the increase in iron content of foods cooked in an iron pot will vary not only with pH, but also with the specific composition of the food. This is also likely to explain some of the high variation in iron content that has been reported for different foods cooked in iron pots (Brittin and Nossaman 1986; Borigato and Martinez 1998).

Salt may also be expected to influence the liberation of iron to the food, because chloride is known to increase corrosion of iron. However, in this study we found no effect of salt on iron release, and chloride apparently forms complexes with iron too weak to increase the rate of the dissolution process under the conditions prevailing in the porridge.

Calculation of the amount of iron liberated to a food of a given composition is almost impossible, because of the nonequilibrium nature of the system. However, it is here demonstrated that the amount of iron taken up by acidic meals containing iron-binding compounds may be substantial, and that iron-binding substances significantly enhance the release of iron to cooked food.

The amount of iron released to the porridges in this study is clinically relevant and could be important in both preventing and treating iron deficiency. A daily serving of 100 g of the porridges with the low pH, resembling fermented porridge, can easily cover the iron needs of a child. Interestingly, the 2 factors associated with an increased release of iron from the pot are also factors that improve iron absorption in the intestine. Both a low pH and organic acids have been shown to improve nonheme iron absorption (Gillooly and others 1983). A continuous intake of large amounts of fermented food prepared in iron pots might, however, result in iron overload. Iron pots are also used for brewing traditional beer in Southern Africa. In a study of African women of childbearing age none of those drinking traditional beer had iron deficiency, while it was common in nondrinkers (Mandishona and others 1999). However, 21% of the beer drinkers had iron overload. The high frequency of severe iron overload with hepatic damage seen among men in

Southern Africa is believed to be caused by drinking large amounts of traditional beer brewed in iron pots (Friedman and others 1990).

Conclusions

THE USE OF IRON POTS IS A CHEAP AND SUSTAINABLE WAY OF PROviding a population with a sufficient iron supply. However, release of iron depends on the specific composition of the food, and before promoting the use of iron pots in a community, the amount of iron released into typical recipes should be examined.

References

Adish AA, Esrey SA, Gyorkos TW, Jean-Baptiste J, Rojhani A. 1999. Effect of consumption of food cooked in iron pots on iron status and growth of young children: a randomized trial. Lancet 353:712-716.

Borigato VM, Martinez FE. 1998. Iron nutritional status is improved in Brazilian preterm infants fed food cooked in iron pots. J Nutr 128:855-859.

Brittin HC, Nossaman CE. 1986. Iron content of food cooked in iron utensils. J Am Diet Assoc 86: 897-901.

Cheng Y J, Brittin HC. 1991. Iron in food: effect of continued use of iron cookware. J Food Sci 56:584-585.

Danish Standardization (Dansk Standardiseringsråd). 1982a. Dansk Standard DS 259 (in Danish). Copenhagen.

Danish Standardization (Dansk Standardiseringsråd). 1982b. Dansk Standard DS 263 (in Danish). Copenhagen.

De-Yu L, Zuan-Guang C, Huan-Qiang L, Mei-Qiong L, Rui L, Lan-Xin L. 1990. Investigation of the amount of dissolved iron in food cooked in Chinese iron pots and estimation of daily iron intake. Biomed Environ Sci 3:276-280.

Fairweather-Tait SJ, Fox TE, Mallillin A. 1995. Balti curries and iron. BMJ 310:1368.

Friedman BM, Baynes RD, Bothwell TH, Gordeuk VR, Macfarlane BJ, Lamparelli RD, Robinson EJ, Sher R, Hamberg S. 1990. Dietary iron overload in southern African rural blacks. S Afr Med J 78:301-305.

Gillooly M, Bothwell TH, Torrance JD, Macphail AP, Deerman DP, Bezwoda WR, Mills W, Charlton RW, Mayet TF. 1983. The effects of organic acids, phytates, and polyphenols on the absorption of iron from vegetables. Br J Nutr 49:331-342.

Glebov AN, Khramov AS, Kirillova EV, Yusupov ST, Sal'nikov YI, Yusupov ZM. 1990. Complex formation and the magnetic properties of homo- and heterovalent iron(II, III) tartrates and citrates. Russ J Inorg Chem 35:1304-1307.

Hamm RE, Shull CM, Grant DM. 1954. Citrate complexes with iron(II) and iron(III). J Am Chem Soc 76:2111-2114.

Mandishona EM, Moyo VM, Gordeuk VR, Khumalo H, Saungweme T,Gangaidxo IT, Gomo ZA, Rounalt T, MacPhail AP. 1999. A traditional beverage prevents iron deficiency in African women of child bearing age. Eur J Clin Nutr 53:722-725.

Mentasti E. 1979. Equilibria and kinetics of the complex formation between iron(III) and alfa-hydroxycarboxylic acids. Inorg Chem 18:1512-1515.

UNICEF/UNU/WHO/MI. 1999. Preventing iron deficiency in women and children: Technical consensus on key issues. Technical Workshop, Oct. 1998. Boston and Ottawa: International Nutrition Foundation and MI.

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