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Strategies to limit colour changes when fortifying food products with iron

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ABSTRACT

Iron, vitamin A, zinc and iodine have been recognized to be the micronutrients with the largest deficiencies worldwide. Among these, iron is highly reactive and may lead to negatively perceived organoleptic changes in products such as dull colour and off-taste. The colour change originated in fortified fruit-containing food products was confirmed to be the result of the complexation of iron and polyphenols. Phenolic compounds with two or more vicinal hydroxy benzyl moieties in their structure, such as catechols and pyrogallols were investigated for their ability to give bathochromic shift phenomena when mixed with iron salts. Furthermore, strategies for limiting colour development were based on: 1) pH adjustment; 2) saturation of polyphenols with unreactive divalent metal ions; 3) suppression of iron reactivity through complexation. Some of these strategies showed a significant improvement in colour stability, with the best results achieved by the latter. The findings in model systems gave a good insight of the mechanisms involved in colour changes, and results were transferable to iron fortified banana puree.

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1. Introduction

Micronutrient malnutrition also defined as hidden hunger affects about one third of world population. As deficiencies in micronutrients are not always clinically detectable, the result might be seen as a health condition degradation of an entire population. Eventually, this could lead to a vicious circle that in the long term results in a negative economic impact for society (Bailey, West, & Black, 2015; Horton & Ross, 2003; Spieldenner, 2010). The two most common forms of micronutrient malnutrition, concerning mainly children and women of childbearing age are vitamin A and iron deficiency (Allen & Haskell, 2002). Food fortification, that is the enrichment of food with dietary minerals and vitamins, has been identified by several organizations, including WHO, as one of the most efficacious and cost-effective solution to prevent hidden hunger at global level (Hoddinott, Rosegrant, & Torero, 2012). Currently, iron deficiency anaemia (IDA) corresponds to the highest deficiency, affecting 20% of the world population (McLean, Cogswell, Egli, Wojdyla, & De Benoist, 2009). Nowadays, mass fortification programs with iron aim to reduce the risk of IDA by fortifying common ingredients such as flour, rice or salt (Pachón, Spohrer, Mei, & Serdula, 2015). However, complementation from food industry via market-driven fortification can additionally increase the effectiveness of this practice (Allen, Benoist, Dary, & Hurrell, 2006). From an industrial perspective, four conditions need to be met to provide effective fortified products,: 1) to use carriers that are credible and consumed regularly by the concerned population; 2) to ensure that organoleptic properties such as colour and taste are not altered; 3) to guarantee high bioavailability once the product is consumed; 4) to keep product prices at an affordable level. A list of carriers for micronutrient fortification, as recommended by WHO, includes cereals, dairy products, juices and condiments (Allen et al., 2006). Fortification of complementary infant food including vegetable or fruit purees can also provide a great contribution to deliver the right amount of micronutrients (Mejia & Bower, 2015). For vegetable and fruit purees, iron fortification often leads to strong colour and taste modification (Hurrell, 1997). Bovell-Benjamin and co-authors showed that organoleptic features should be considered to be as important as bioavailability for successful fortification (Bovell-Benjamin & Guinard, 2003). For example, consumers use colour as a key quality indicator for freshness (Clydesdale, 1998) and food industry needs to ensure this aspect (Galaffu, Bortlik, & Michel, 2015).

Fig. 1 shows the negative impact of iron fortification on the colour of some sensitive foods and in the case of banana, the product identity is completely lost.

The reason behind is the high amount of polyphenols reacting with iron. Polyphenols are secondary metabolites present in many plants, especially fruits and vegetables, and are mostly responsible for imparting colour to these.

Chemical mechanisms for colour changes in products containing polyphenols are well reported in the literature. The main mechanism is the chelation of Ferrous or Ferric ions with electron rich phenolic oxygen, resulting in blue/black products due to charge transfer phenomena (Elhabiri, Carrër, Marmolle, & Traboulsi, 2007; Khalil, Al-Zahem, & Al-Qunaibit, 2013; Lattanzio, Cardinali, & Linsalata, 2012).

The general approach to avoid this phenomenon is to use poorly soluble iron compounds. Although this might improve colour stability, it often has a negative impact on bioavailability. Fig. 2 summarizes the

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Fig. 1. Effect of iron fortification on food products containing sensitive components. The value of ΔEab corresponds to the total colour deviation based on the CIELab standard.

expected stability and relative absorption of common commercial iron salts as a function of their solubility in gastric conditions. Thus the selection of an iron compound with high absorption that causes no sensory changes when added to the food is not straightforward.

Nutritionists and Key Opinion Leaders (KOLs) agree that bioavailability is essential for enabling effective fortification. Recently, this has been further emphasised by issues related to inflammation of the intestinal tract when using high doses of poorly bioavailable iron forms (Jaeggi et al., 2014).

The food industry makes great efforts to develop solutions to improve organoleptic properties of products and ensure good bioavailability where iron fortification is applied (Hurrell, 2002; Uauy, Hertrampf, & Reddy, 2002). The main approach to achieve this is based on limiting the contact of iron with reactive molecules through physical or chemical means (Hurrell & Egli, 2007). The most common practice, as mentioned earlier, is to use poorly soluble iron salts (e.g. Ferric Pyrophosphate) and add ascorbic acid to enhance bioavailability (Davidsson, Kastenmayer, Szajewska, Hurrell, & Barclay, 2000). For more soluble iron salts, micro-encapsulation can be a winning strategy for dry foods. Nevertheless, the protection is not guaranteed once the product is reconstituted in water and cooked (Hurrell et al., 1989). Moreover, encapsulated

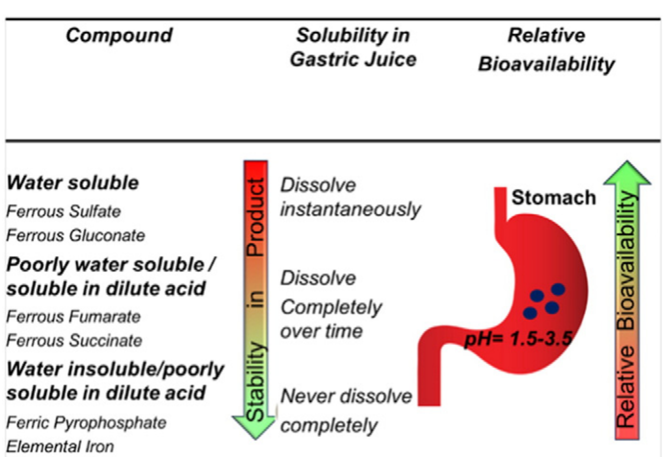

Fig. 2. Stability and bioavailability relationship of commercial iron sources for food fortification.

iron is costly, and so may result in an undesirable price increase (Hurrell & Egli, 2007). A more affordable alternative for food manufacturers is the development of delivery systems based on food ingredients already present in recipes (Zuidam, 2012). Even so, the stability in high moisture food after heat treatment is generally lost. Strategies based on complexation generally lead to more stable and bioavailable solutions with less or no impact on colour and taste. A prominent example of this approach is the use of Sodium Ferric EDTA. Nevertheless due to high price and lack of consumer acceptance its use is limited (Whittaker, Vanderveen, Dinovi, Kuznesof, & Dunkel, 1993).

The work described in this article uses a model system approach based on polyphenols involved in colour changes with Ferrous Sulphate. The role of pH, polyphenol concentration, heat treatment and stability constants on the formation of Iron:Polyphenols complexes was investigated. The results of this investigation were used as a guide to identify promising strategies to limit Iron:Polyphenols complexes formation, thereby minimizing colour changes in commonly iron-fortified foods. Advantages and drawbacks of these strategies are discussed in detail.

2. Materials and methods

2.1. Materials

Catechin, Epicatechin, Epigallocatechin and Gallic acid were supplied by Sigma Aldrich.

Values of pKa1 and pKa2 in Table 1 were collected from literature data (Arts, Van De Putte, & Hollman, 2000; Herrero-Martínez, Sanmartin, Rosés, Bosch, & Ràfols, 2005; Mentasti & Pelizzetti, 1973; Perron & Brumaghim, 2009).

Ferrous Sulphate heptahydrate and Ferric Pyrophosphate were supplied by Dr. Paul Lohmann AG. Homogenized Banana puree was produced in Cartago Factory (Costa Rica) from fresh ripened bananas that once mashed were stabilized with ascorbic acid, sieved to remove seeds and thermally processed in aseptic packaging.

0.1 M Acetate buffers at pH from 3.5 to 5.5 were prepared as described in literature (Beynon & Easterby, 1996). Potassium Thiocyanate, Magnesium Gluconate, Calcium Gluconate and Zinc Sulphate heptahydrate were purchased from Sigma Aldrich. Other chemicals such as Acetic acid, Sodium Acetate, Sodium Hydroxide, Hydrochloric acid, Sodium Bicarbonate, Disodium Hydrogen Phosphate, Citric acid

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