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Effect of microencapsulated ferrous sulfate particle size on Cheddar cheese composition and quality

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ABSTRACT

Iron-fortified Cheddar cheese was manufactured with large microencapsulated ferrous sulfate (LMFS; 700–1,000 μm in diameter) or small microencapsulated ferrous sulfate (SMFS; 220–422 μm in diameter). Cheeses were aged 90 d. Compositional, chemical, and sensory characteristics were compared with control cheeses, which had no ferrous sulfate added. Compositional analysis included fat, protein, ash, moisture, as well as divalent cations iron, calcium, magnesium, and zinc. Thiobarbituric acid reactive species assay was conducted to determine lipid oxidation. A consumer panel consisting of 101 participants evaluated the cheeses for flavor, texture, appearance, and overall acceptability using a 9-point hedonic scale. Results showed 66.0% iron recovery for LMFS and 91.0% iron recovery for SMFS. Iron content was significantly increased from 0.030 mg of Fe/g in control cheeses to 0.134 mg of Fe/g of cheese for LMFS and 0.174 mg of Fe/g of cheese for SMFS. Fat, protein, ash, moisture, magnesium, zinc, and calcium contents were not significantly different when comparing iron-fortified cheeses with the control. Iron fortification did not increase lipid oxidation; however, iron fortification negatively affected Cheddar cheese sensory attributes, particularly the LMFS fortified cheese. Microencapsulation of ferrous sulfate failed to mask iron's distinct taste, color, and odor. Overall, SMFS showed better results compared with LMFS for iron retention and sensory evaluation in Cheddar cheese. Results of this study show that size of the microencapsulated particle is important in the retention of the iron in the cheese and its sensory attributes. This study provides new information on the importance of particle size with microencapsulated nutrients.
Key words: Cheddar cheese, microencapsulation, iron fortification, sensory, lipid oxidation

INTRODUCTION

Globally, iron, iodine, folate, vitamin A, and zinc are the most deficient micronutrients in the diet (Bailey et al., 2015). The most susceptible populations for micronutrient deficiencies are children and pregnant women (Fulgoni et al., 2011; Keast et al., 2013; Malpeli et al., 2013). The World Health Organization (WHO, 2016) reported that one-third of the world's population, 2 billion people, suffers some level of iron deficiency. Iron plays an important role in the functionality of the hemoglobin protein, part of the red blood cell, which is responsible for carrying oxygen throughout the body (Sadava et al., 2008). Anemia, premature births, maternal and fetal death, low immunological competency, and impaired psychomotor development are some of the consequences of consistent low iron intake and absorption (Cherayil, 2010; Georgieff, 2011).

The 2 most widely used approaches to fighting malnutrition, including iron deficiency, are food fortification and micronutrient supplementation (Allen et al., 2006). Currently food fortification is the most promising and cost-effective strategy to reduce malnutrition on a global scale (Horton et al., 2008; Fiedler and Macdonald, 2009). Due to its popularity, cheese can be the perfect vehicle for iron-fortification programs. In the United States, the majority of milk is consumed as cheese, fluid milk, ice cream, yogurt, and as other dairy products (IDFA, 2016). In 2013, per capita consumption of natural cheeses was 15.3 kg (IDFA, 2016). Milk and cheese are nutrient-dense foods; cheese is often the recommended meat alternative in school lunch programs and in vegetarian diets. However, milk, cheese, and other dairy products are naturally low in iron; one serving (28 g) of Cheddar cheese provides approximately 0.04 mg of iron (USDA National Nutrient Database for Standard Reference, 2016).

Iron is a challenging micronutrient to add to foods due to its potential to negatively affect the organoleptic properties (Allen et al., 2006). Recently, microencapsulated iron compounds have received attention because of their potential to increase iron bioavailability and to reduce sensory changes in foods (Dubey et al., 2009;

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Frankel 2014). Zhang and Mahoney (1989, 1990), pioneers in dairy fortification studies using iron, fortified Cheddar cheese with different iron compounds and reported that it is possible to produce good-quality iron-fortified Cheddar cheese; however, the iron fortificants that produced good-quality cheese have limited bioavailability (Allen et al., 2006). Rice and McMahon (1998) fortified Mozzarella cheese with casein-bound iron, whey protein-chelated iron, or $FeCl_3$-iron complex compounds. Although a trained sensory panel detected slight increase in metallic, oxidized, and off flavors compared with control cheeses, these differences were not statistically significant; those authors did not report on the bioavailability of the iron compounds used. Motzok et al. (1975) reported that bioavailability of reduced iron is affected by particle size. Boccio et al. (1997) reported higher bioavailability for encapsulated ferrous sulfate compared with nonencapsulated iron compounds in fluid milk studies, but no overall product acceptability or its sensory characteristics were reported. Wegmüller et al. (2004) found that reducing particle size of microencapsulated ferric pyrophosphate, from 21 to 0.5 μm, increased bioavailability by 50%, leading to search for ideal particle size for optimal absorption and bioavailability.

Iron can further be a challenging nutrient to add to milk and dairy foods due to its potential to displace other divalent cations in the milk system (Vasudevan et al., 2002). Milk minerals have an important role in cheesemaking, such as coagulation, whey draining, and curd texture (Patiño et al., 2005). Gonzalez-Martin et al. (2009) reported that mineral profile in cheese played a key role in cheese yield and ripening time. Minerals such as calcium, for example, are in a delicate equilibrium between the colloidal calcium phosphate associated with the casein micelles and soluble calcium phosphate found in water phase. Displacement of calcium with another divalent cation can shift the calcium equilibrium moving the colloidal calcium to soluble phase. Kahraman and Ustunol (2012) suggested that when Cheddar cheese is fortified with zinc sulfate there is displacement of calcium with zinc at the casein micelle level due to loss of calcium in the whey with an increase in zinc concentration in the fortified cheese. The major milk protein caseins have strong affinity to divalent cations; however, binding affinity depends on different factors including pH, ionic strength, temperature, and phosphate group content (On-Nom et al., 2010).

The goal of fortification is to increase nutritional content in a food without compromising other nutrients. If any mineral displacements occur in cheese, the displaced divalent cation (i.e., calcium, magnesium, or zinc; nutritionally important and present in significant amounts in cheese) will be lost during the whey-draining and cheese-pressing steps. Currently, limited literature is available on divalent cation balance disturbances when fortifying cheese with minerals such as iron.

We hypothesized that fortification of Cheddar cheese with microencapsulated ferrous sulfate would increase iron content with no major compositional changes. Additionally, reducing microencapsulated ferrous sulfate particle size would increase iron retention and reduce the effect on sensory attributes. Thus, the objectives of our study were to evaluate the effect of microencapsulated ferrous sulfate with large and small particle sizes on Cheddar cheese quality, and to assess composition, lipid oxidation, and sensory differences. Divalent cation balance disturbances when fortifying Cheddar cheese with iron was also evaluated.

MATERIALS AND METHODS

Microencapsulated Ferrous Sulfate Salts

Microencapsulated ferrous sulfate with diameters of 700 to 1,000 and 220 to 422 μm per particle [large (**LMFS**) and small (**SMFS**), respectively] were obtained from Paul Lohmann Inc. (Emmerthal, Germany). Both iron salts were microencapsulated with 1 layer of hydrogenated palm oil. Iron salts were sterilize based on the current good manufacturing processes, pharmacopoeia, and international food regulations followed by the manufacturer. This was verified in our laboratory by standard microbial plate counts.

For the cheese-fortification dosage, 30% (4.5 mg) of the iron recommended daily allowance (**RDA**) per serving was selected, assuming an average RDA of 15 mg of Fe/d in the United States. Table 1 shows the amount of iron salt added to Cheddar cheese based on the iron content of each fortificant.

Table 1. Ferrous sulfate treatments and fortification dosage

Treatment	Fe^{+2} Source	Diameter, μm	Fe^{+2} content, %, wt/wt	Fortification dosage[1]
Control	—	—	—	—
LMFS	Large microencapsulated ferrous sulfate	700–1,000	16.8	0.95
SMFS	Small microencapsulated ferrous sulfate	220–422	9.0	1.78

[1]Grams of microencapsulated ferrous sulfate/kg of Cheddar cheese.