Microencapsulation-based technologies for effective delivery of micronutrients in fortified stable foods

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INTRODUCTION

Although there is enough food to meet the nutritional needs of the world's growing population, WHO (World Health Organization, 2000) estimates that about one-third of the world's population suffers from micronutrient deficiency. This "hidden hunger" occurs in both under-nourished and over-fed populations. Health problems associated with poor nutrition seen in both industrialized and developing countries, include retarded learning ability in children and impaired work capacity in adults, as well as increased risk to infectious and chronic diseases. Micronutrient-based malnutrition has greatly affected the social and economic development, and has been recognized as one of the major global problems.

A healthy, balanced diet is the primary solution to poor nutrition, but is constrained by many social and economic factors. Traditional lifestyles lead to resistance to dietary changes; to overcome these requires education often for several generations. Food fortification-based interventions, when designed properly, can be cost-effective in alleviating the problems associated with poor nutrition. Food fortification involves the production of novel food products that balance a population's nutritional profile, leading to "optimized nutrition".

Although food fortification has been practiced for many years, there are technical challenges, specifically related to multiple micronutrient fortification. Staple foods, such as salt, sugar, and rice, are good vehicles for micronutrient fortification, since the added micronutrients reach the largest number of people cost-effectively. Food fortification can be cost-effective to initiate and maintain. However, staple foods are typically presented to the consumer as solids with particle sizes ranging from several microns to several milimeters. To prevent particle segragation, which may result in potential under- or over-dosing, micronutrients must be added in forms that either stick to the food particles, or match the particle size, and if possible, the particle density of the food. Succesful food fortification processes require that the added micronutrients are evenly distributed and are unnoticeable to the consumer. Thus the complete delivery system must match the food in colour and appearance, and must not alter the food flavour and taste.

Despite the relatively small quantities of micronutrients required, the safe and effective delivery of these ingredients is challenging due to 1) the disagreeable taste and appearance associated with most active ingredients, 2) chemical instability of most vitamins; 3) undesirable interactions with food components and with other micronutrients; 4) need to control bioavailability of the added actives in the digestion system, and 5) potential degradation of the functionality of the food vehicle by the fortification process. Therefore, innovative technologies are required to ensure effective delivery of micronutrients in forms that are stable and bioavailable through food processing, distribution, preparation, and consumption.

Microencapulation technology is a promising approach to producing stable, viable systems. During the past four years we have developed an extrusion-based microencapsulation technology platform, and have demonstrated its technical feasibility in multiple micronutrient fortification of typical staple foods, including salt, sugar, and rice. This technology platform combines extrusion

agglomeration, colour-masking, and polymer encapsulation, and is adaptable to developing customized delivery systems for broader applications, from food fortification to nutraceutical delivery in functional foods. Specific research results in the study of double fortified salt are presented in the following section.

MATERIALS AND METHODS

Food-grade ferrous fumerate, particle size of ~50 µm and ~100 µm, were obtained from Dr. Paul Lohmann Chemicals, Germany and Glatt Air Technique, NJ, USA, respectively. Binder materials used in the study, including rice flour, regular wheat flour, durum wheat flour, and durum semolina were procured from local supermarkets. TiO_2 was used as the colour-masking agent and obtained from Sigma-Aldrich, USA. Several coating polymers were used to encapsulate colour-masked iron particles to form the final iron premixes. They were obtained from Dow Chemicals, Colourcon, Degussa, respectively. Other formulation components and analytical reagents were used at food-grade or analytical grade, and obtained from Sigma-Aldrich, USA. Food-grade, iodized salt (0.01% I_2 from potassium iodate) was provided by Kensalt, Kenya through MI.

Production of microencapsulated ferrous fumarate premix

The microencapsulated iron premix was made by a newly proposed process, as shown in Figure 1. A wet mixture of FeFum powder and the selected binder was first extruded to form filaments with 0.5 mm diameter, which were then cut into tiny cylindrical particles. After drying, the particles were applied with a colour-masking agent, TiO_2. This step was followed by coating with selected polymers. The resulting iron premixes were blended into iodized salt to form DFS.

Iron premix physical characteristics and surface morphology

The iron premix samples were examined visually and using an Intel$^{®}$ Play^{TM} QX3 Computer Microscope. The surface morphology of the iron premix was examined using a Hitachi Scanning Electron Microscope (Model S-2500). Bulk density and particle density of the iron premix were also measured by conventional methods.

DFS sample preparation and stability test

Kenyan iodized salt with a nominal iodine concentration of 100 mg/kg was used to prepare the double fortified salt samples. The formulated iron particles after each processing stage were added into this salt in a ratio varying from 1:160 to 1:200 to produce double fortified salt (DFS) samples with the target iron concentration of ~1000 ppm. Ferrous fumarate powder without any treatment was used to prepare a negative control. The salt samples were stored in an environmental chamber at 40^{o}C and 60% relative humidity (RH) for one year and analyzed for iodine and ferrous iron at the beginning and after 1, 3, 6, and 12 months.

Iron and iodine analysis

Total and ferrous iron content in the iron particles were determined by spectrophotometry (Harvey, Smart, & Amis, 1955), as a complex with 1,10-phenanthroline. The iodine content in the double fortified salt samples containing the developed iron premix was determined based on the iodometric titration method (AOAC method 33.149). Iron *in vitro* digestibility was approximated from the rate of dissolution of iron in the simulated gastric acid (pH 1 HCl solution) (USP General Chapter 711; Swain et al., 2003).

Statistical analysis

Data from chemical assays were obtained from three to four replicates, and reported as the mean value ± standard deviation (SD). One-way ANOVA was used to examine the statistical significance between the sample performances, using the Origin Pro 7.5 Program Package.

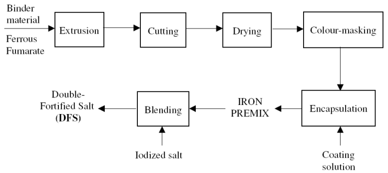
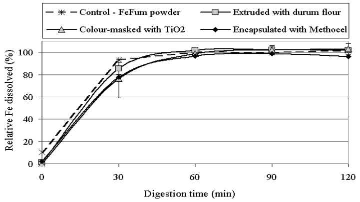


Figure 1 Schematic process flow for making microencapsulated ferrous fumarate



At 30 min digestion, there is no significant difference between the extruded, colour-masked, and encapsulated iron particles (p>0.05).

Figure 2 Effect of each step of the encapsulation process on iron digestibility

RESULTS AND DISCUSSION

Iron premix physical properties

The formulated iron premix had desirable physical characteristics – matching shape, size, colour, and even density of salt grains. When blended into iodized salt to form double fortified salt, it was indistinguishable. Digital pictures of the salt samples taken by an optical microscopy will be presented in the conference.

Iron in vitro bioavailability

FeFum was chosen mainly due to its high bioavailability, it is then hoped the encapsulation process would not cause negative impact on this property. As shown in Figure 2, the iron particles after different processing steps had virtually the same dissolution profiles as the iron powder when digested in the pH1 HCl solution, which is a close approximation of the action of gastric juice. This suggested the microencapsulated iron premix achieved excellent digestibility.

Iodine stability in DFS

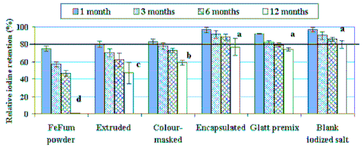
As shown in Figure 3, compared to the original iodized salt, the incorporation of microencapsulated iron premix did not cause extra loss of iodine. In contrast, the direct addition of the iron powder resulted in the loss of almost all of the added iodine. Each step in the formation of the iron premix had an additive positive impact on the stability of the system, resulting in a very stable salt.

Reduced interaction between iodine and ferrous iron in DFS

As indicated in the literature (Diosady et al., 2002), ferrous compounds can react with iodate salts, resulting in the formation and eventually loss of iodine and the oxidation of iron to its ferric form, as described by the following equation:

$$2\,I^{5+} + 10\,Fe^{2+} \rightarrow I_2 + 10\,Fe^{3+}$$

Correlation analysis was used to examine the losses of both iodine and ferrous iron in DFS after one year storage (Figure 4). Clearly, there was interaction between iodine and iron; however, the proposed encapsulation process could successfully impede or prevent this reaction.



The results of the column ☐ with different superscripts are significantly different at $p < 0.05$. The values between each column are significantly different ($p < 0.05$) in the groups of FeFum powder, extruded, newly encapsulated, but not in the groups of colour-masked, Glatt premix and blank iodized salt.

Figure 3 Iodine stability in DFS samples containing various FeFum forms after one-year storage at 40°C and 60% RH. (Note: the results are the mean values obtained from three or four replicates, and the error bars represent the standard deviations.)

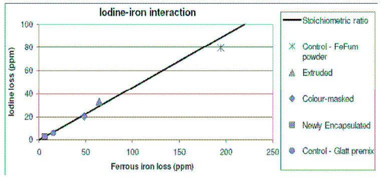


Figure 4 Iodine-iron interaction in DFS – correlation analysis between iodine and ferrous iron losses in the DFS samples containing various iron particles after one year storage under 40°C and 60% RH

CONCLUSIONS

The study has demonstrated the feasibility of the extrusion-based technology platform for making microencapsulated FeFum premix with desired physical-chemical properties suitable for salt double fortification. The overall results have confirmed that microencapsulation technology can be used effectively to fortify staple foods with a combination of reactive micronutrients. The microencapsulation-based technology platform is adaptable to formulating customized delivery systems for delivering active ingredients in a broad range of applications, and promises to bring immediate benefits in combating micronutrient deficiencies, that will have far reaching effects in health and social development.

REFERENCES

- Diosady, L. L., et al. (2002) *Iodine stability in salt double fortified with iron and iodine*. Food and Nutrition Bulletin 23: 196-207.
- Harvey, A. E., et al. (1955) *Simultaneous spectrophotometric determination of Iron (II) and total iron with 1, 10-phenanthroline*. Analytical Chemistry 27: 1-8.
- Official Methods of Analysis - Association of Official Analytical Chemists (AOAC), 15th Ed., Arlington: The AOAC Inc., 1990. Method 33.149.
- Swain, J. H., et al. (2003) *Bioavailability of elemental iron powders to rats is less than bakery-grade ferrous sulfate and predicted by iron solubility and particle surface area*. The Journal of Nutrition 133(11): 3546-3552.
- USP: Dissolution (Chapter 711), USP29-NF24 page 2673. Parmacopeial Forum: 31(1): 398.
- World Health Organization (WHO, 2000) – *Malnutrition: The global picture*. In: Nutrition for health and development, a global agenda for combating malnutrition.