

O7-4 Microencapsulation-based food fortification through Ultra Rice® technology

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INTRODUCTION

Micronutrient deficiencies are severe nutritional problems affecting over one-third of the world's population, mostly in developing countries. Food fortification is a highly cost-effective solution to the problem. Despite the relatively small quantities of vitamins and minerals required, there are major technical challenges in their safe and effective delivery. Innovative technologies are required to ensure the stability of added micronutrients through processing, distribution, retail and food preparation, and ultimately to ensure their effective delivery to the body in safe, bioavailable forms.

Microencapsulation technologies promise to fulfill all these technical needs. An extrusion-based microencapsulation technology platform has been developed (Fig. 1), which demonstrated the technical feasibility of multiple micronutrient fortification of staple foods, such as salt, sugar, and rice. This technology combines several unit operations based on concepts of chemical engineering, and is adaptable to developing customized delivery systems for a broad range of active food ingredients.

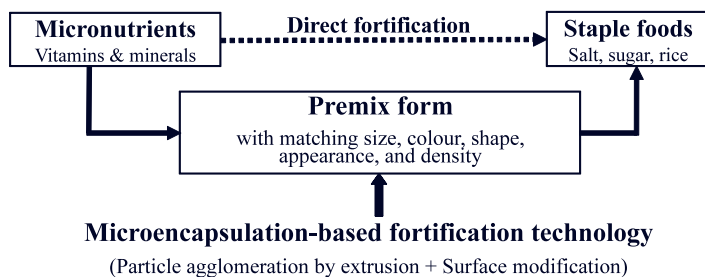


Figure 1: General research approach

This approach has been successfully combined with Ultra Rice® technology for delivering multiple micronutrients to rice with a reconstituted, nutrient-fortified rice premix made by extrusion, which resembles the shape, size, and appearance of common rice kernels. When formulated with appropriate micronutrients and blended at a 1:100 or 1:200 ratio with normal market rice, the process delivers the required micronutrients to urban rice-based diets in a form indistinguishable from unfortified rice. This novel technology has a unique advantage of protecting the added micronutrients within the manufactured grains from losses during storage, washing, and cooking. Compared to previous rice fortification techniques, such as powder enrichment after milling and surface coating of micronutrients, Ultra Rice® technology provides better results in terms of nutrient stability, consumer acceptability, and hence nutrient absorption and clinical effectiveness.

MATERIALS AND METHODS

Materials

Rice flour and consumer shortening (Crisco, Procter and Gamble, Canada) were procured from a local supermarket. Vitamins including vitamin A palmitate, thiamine, and folic acid were obtained from BASF Chemicals (Canada). Ferric pyrophosphate and zinc oxide were obtained from Dr. Paul Lohmann Chemicals (Germany). Sodium alginate and calcium salts (CaCl_2 and CaSO_4) were used as cross-linking agents in forming extruded grains with desired grain structure and integrity, and were obtained from ISP Alginates (USA) and Sigma-Aldrich (Canada), respectively. Antioxidants used in the study were obtained from Sigma-Aldrich (Canada), including butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), ascorbic acid, citric acid, and sodium tripolyphosphate (STPP). All formulation components were food grade. The analytical reagents used for vitamin and mineral analyses were obtained from Sigma-Aldrich (Canada) at ACS analytical grade.

Rice premix preparation by extrusion

Rice flour was blended with selected micronutrients and other formulation components. To the dry mixture, water and melted shortening containing fat-soluble antioxidants were added and blended to form an extrudable dough. The dough was then kneaded and extruded to form rice-shaped kernels, using a commercial pasta extruder, La Monferrina P12 (Italy). The reformed grains were dried at 45°C for >20 hours, and then screened. The grains with desired size were used for storage stability tests. Detailed procedures were reported in Li et al. (2009).

Analytical methods

Vitamin A and thiamine were determined based on spectrofluorometry using the Association of Official Analytical Chemists method 43.003 and 942.23, 953.17 (AOAC Fifteenth Edition, 1990), respectively. Folic acid was measured by spectrophotometry based on a colored complex formed by reacting folic acid with several reagents in a series of sequential steps. Iron and zinc contents were determined by atomic absorption spectrophotometry (AAS). Detailed analytical protocols can be found in Li et al. (2008 & 2009). The physical characteristics of the extruded rice grains, including appearance, texture, and surface morphology were examined by optical microscope and scanning electron microscope (SEM). The grain colour was measured using a Hunter $L^*a^*b^*$ spectrophotometric system, where L^* stands for the lightness, a^* for the gradation from red (+) to green (-), and b^* for the gradation from yellow (+) to blue (-).

RESULTS & DISCUSSION

Optimized antioxidant system for stabilizing vitamin A

Vitamin A readily degrades in the presence of many environmental factors, by an apparent first-order mechanism. To develop a stable Ultra Rice[®] formulation for vitamin A delivery, we tested ten formulations using various combinations of hydrophilic and hydrophobic antioxidants. After a 6-month storage stability test at high temperature and humidity, the best formulation was identified, which retained $\geq 70\%$ of the added vitamin A (formulation 10 in Fig. 2). It contained BHA and BHT as the fat-soluble antioxidants, ascorbic acid as the water-soluble antioxidant, and citric acid and STPP as metal chelating agent and moisture stabilizer. The optimized antioxidant system consists of generally accepted food additives with low prices, which greatly improves the commercial viability of Ultra Rice[®] premix as a rice fortificant.

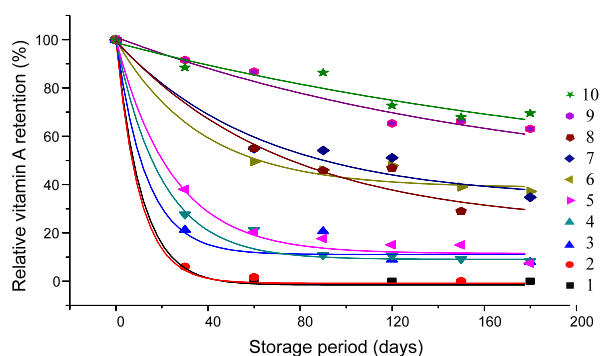


Figure 2: Relative vitamin A retentions in rice formulations containing various antioxidant systems over 6 months storage at 35°C and ~60% RH

Iron-bearing multiple-fortified formulation

Based on the optimized antioxidant system, we then developed a stable formulation containing iron, zinc and several B vitamins. The choice of iron compound had great impact on stability of added vitamins and grain physical characteristics. When ferric pyrophosphate was used as the optimal iron source, $>95\%$ of thiamine and $>75\%$ folic acid were retained after 9 months storage at 40°C and 60% RH. The extruded grains had similar L*, a*, and b* values to that observed with polished white rice, indicating that a stable fortified rice product with excellent consumer acceptability can be obtained by blending the extruded rice premix into normal market rice. Detailed results were reported in Li et al. (2008).

Process improvement

The original Ultra Rice[®] production process involves a coating step after extrusion (Fig. 3 on the left). The extruded rice grains containing alginate were coated by spraying a CaCl₂ solution at the surface before drying. The ensuing cross-linking reaction between alginate and calcium forms a hardened shell at the grain surface. This diffusion-driven gelation forms a cross-linked network, analogous to a “fish-net” with pore size of $\sim 1 \mu\text{m}$, which maintains the grain structure and prevents the bigger starch granules from leaking out during food preparation.

However, this process creates some problems – the external coating step is hard to control as uniform distribution of calcium ions is difficult. The hardened grains tend to crack and disintegrate during cooking as the starch expands against the rigid alginate shell. These constraints have greatly hindered the commercialization of the technology.

We improved the process by developing a controlled internal gelation technique (Fig. 3 on the right). Sodium alginate and a calcium salt (with limited solubility, e.g. CaSO₄) were added to the formulation prior to extrusion. With the aid of STPP, a sequestrant, the cross-linking reaction between alginate and calcium was slowed, with hardening completed only at the end of extrusion. This not only simplified the process by removing the post-extrusion coating step, but also resulted in improved grain integrity as all of the alginate could be converted to a completely inter-connected structure throughout the grain, which enclosed and protected the added micronutrients within the rice matrix.

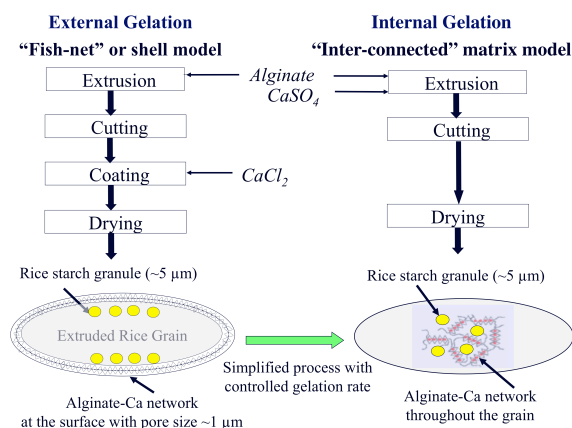


Figure 3: Schematic process flow for external (left) and internal (right) gelation techniques

CONCLUSIONS

Ultra Rice[®] now contains a robust antioxidant system for stable vitamin A fortification, and has been formulated for multiple-nutrient fortification (iron, zinc, thiamin and folic acid). Further processing refinement has resulted in improved organoleptic properties and particle integrity of the reconstituted kernels, ultimately improving its commercial and consumer acceptability. Ultra Rice[®] has been successfully introduced to Colombia, Brazil, India, and China under the supervision of Program for Appropriate Technology in Health (PATH). Recently the Ultra Rice[®] technology has been selected as a 2009 Tech Award Laureate, due to its innovative approach to addressing global nutritional problems.

REFERENCES

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