Microencapsulation of omega-3 oils with food biopolymers: *in-vitro* and *in-vivo* validation

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INTRODUCTION

The delivery of omega-3 oils through food products has been facilitated with the development of new microencapsulated omega-3 powder ingredients, many of which use food biopolymers as encapsulating matrices (Drusch & Mannino, 2009; Sanguansri & Augustin, 2010). Food-grade biopolymers, including proteins and some carbohydrates, have good film-forming and emulsifying properties that make them well suited as encapsulant materials. Furthermore, they may be modified by conventional and emerging food processing techniques (i.e. heat, shear, pressure) to enhance their encapsulating properties. Many studies have shown that microencapsulated omega-3 oil formulated with food biopolymers protect the oil against oxidation during storage of the ingredient and processing when incorporated into food products without compromising sensory properties of the food. However for the microencapsulated oils to exert their desired biological effect, they must also be bioavailable after consumption. This paper discusses the journey from introduction of a concept which capitalised on the encapsulating properties of modified food biopolymers for protecting omega-3 oils against oxidation to testing the release of the oil in food products for *in-vitro* and *in-vivo* validation.

MATERIALS AND METHODS

Preparation of microcapsules
The preparation of microcapsules was based on formulation, processing and drying of oil-in-water emulsions stabilised by food grade modified food proteins and carbohydrates (Sanguansri & Augustin, 2001; Augustin et al., 2005). The encapsulating properties of proteins were modified by the heat treatment of proteins in the presence of a reducing carbohydrates prior to (Heat Aqueous phase) or after the formation of an emulsion (Heat Emulsion). In some cases a resistant starch (RS) modified using physical processes to increase reducing sugar groups and enhance film-forming and emulsion stabilisation properties was used. Emulsions were formulated with the unmodified or modified biopolymers for production of high oil loading microencapsulated omega-3 oil powders.

In-vitro and in-vivo release properties
In-vitro release properties of neat microcapsules and within food matrices were evaluated using adapted UPS24 *in-vitro* methodology (Shen 2011).. *In-vivo* studies were conducted with healthy volunteers and with ileostomy volunteers.

RESULTS AND DISCUSSION

In-vitro release of neat nicrocapsules (50% oil) & In-vivo release when in food with healthy volunteers
The formulation of microcapsules with proteins (whey protein, casein, soy protein) in combination with sugars (oligosaccharide, dried glucose syrup), modified resistant starch (RS) or pectin influenced *in-vitro* lipolysis of encapsulated oil. The free fatty acid (FFA) obtained from lipolysis of microencapsulated oil ranged from 11-63% after sequential exposure to simulated gastric fluid (SGF) and simulated intestinal fluid (SIF) (Table 1). However, there was similar bioavailability of oils delivered as free oil and within different encapsulation matrix formulations when delivered in a dairy-based Smoothie (Figure 1).

Table 1: In-vitro release of microcapsules (50%oil)

Biopolymer encapsulant	%FFA
A: Casein-RS (Heat emulsion)	11
B: Casein-RS (Heat aqueous phase)	51
C: Casein-Oligosaccharide-Dried glucose syrup (Heat aqueous phase)	59
D: Whey protein -RS (Heat aqueous phase)	63
E: Soy protein-Pectin	55

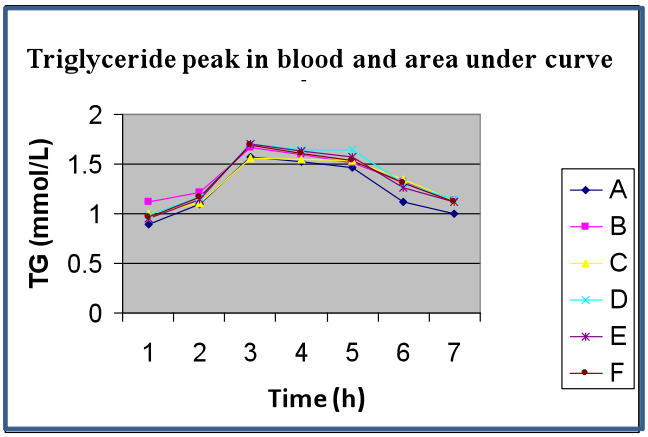

Figure 1. Bioavailability of microencapsulated oil (A-E as given in Table 1) and free oil (F) added to a food matrix (30g oil as microcapsules or free oil in 250 mL dairy-based Smoothie). TG=triglyceride.

Effects of food matrix on oil release in-vitro and in-vivo with ileostomy volunteers

Exposure of a neat microencapsulated fish oil powder (25% oil) or food matrices fortified with the microencapsulated fish oil to SGF resulted in minimal release of eicosapentaenoic acid, EPA (4-6%) and docosahexaenoic acid, DHA (<2%). Sequential exposure of microencapsulated omega-3 oils to SGF and SIF caused >70% (EPA/DHA) release from the neat fish oil powder and orange juice or yoghurt fortified with the fish oil powder; and 58-60% (EPA/DHA) release from cereal bar fortified with fish oil powder (Shen 2011). These results showed that the food matrix influenced the release of EPA and DHA during *in-vitro* digestion (Figure 2).

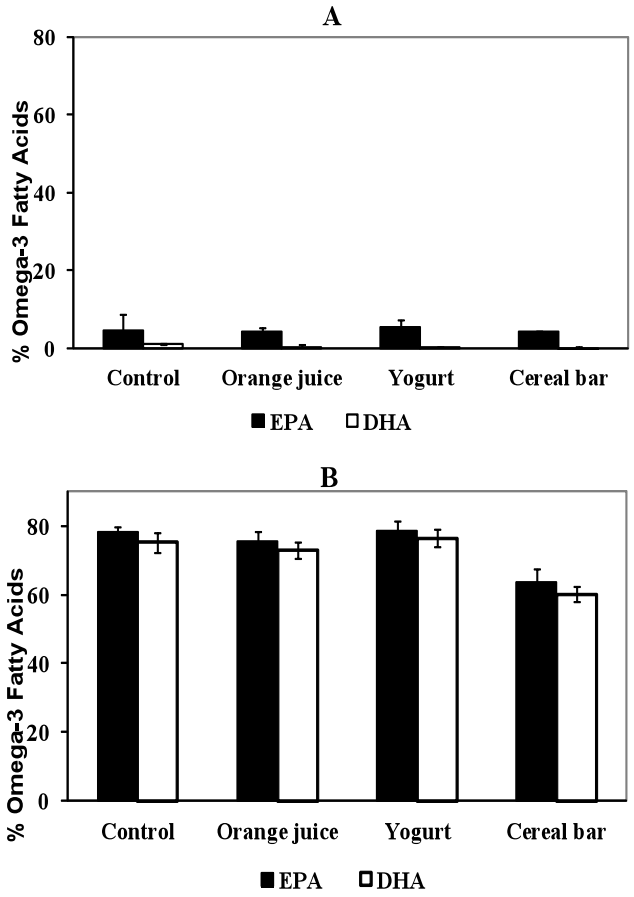

Figure 2. Omega-3 fatty acids released from neat fish oil powder (control) and foods fortified with microencapsulated fish oil after exposure to (A) SGF and (B) SGF + SIF. Oils were encapsulated within a heated mixture of casein, glucose and modified RS (Data from Shen et al., 2011).

For the *in-vivo* study, ileostomy volunteers were given a soft gelatine capsule (1000 mg fish oil with 27-28% long-chain polyunsaturated fatty acids) and foods (orange juice, yogurt and cereal bar) fortified with microencapsulated fish oil (at a dose of 1000 mg fish oil in microcapsules per serving). The omega-3 fatty acids in ileal effluents were collected over 24 h after ingestion of the capsule and fortified foods. Only <2% of the administered dose of omega-3 fatty acids was recovered in the ileal effluent within 24 h, irrespective of the food delivery vehicle for the omega-3 oils.

CONCLUSIONS

While the *in-vitro* methods used in the study provide insights into possible mechanisms and release of microencapsulated oils, the results do not correlate with their bioavailability *in vivo*. The main finding is that omega-3 oils delivered as microencapsulated oils stabilised by food biopolymers and incorporated into food products are bio-equivalent to free oil added into food products and omega-3 oil within a gelatine capsule.

The main purpose of microencapsulation of omega-3 oils with food biopolymers is to protect them during storage and to enable their delivery into functional foods without compromising the sensory properties of the food and the bioavailability of the oil. Previous studies have confirmed that microencapsulation protects the omega-3 oils from oxidation and development of off-flavours (Sanguansri 2001). Formulation of omega-3 oil microcapsules for improved oxidative stability does not affect the bioavailability of the oils after ingestion. The *in-vivo* data validates the approach of delivering microencapsulated oils through food.

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