Encapsulating bioactive ingredients

MICRO-ENCAPSULATION HAS BEEN USED TO INCORPORATE OMEGA-3 OILS IN SMOOTHIES

The food industry is interested in incorporating bioactive ingredients in their products. These ingredients need to be protected from degradation and undesirable interactions with food components, and cannot usually be added directly to food without compromising food quality. Nano- and micro-encapsulation offer solutions to these problems. Mary Ann Augustin and Luz Sanguansri write

The functional food industry is increasingly aiming to add bioactive components to food, particularly those foods that are consumed as part of the normal diet.

Food bioactives are physiologically active components of plant or animal origin which have a role in health beyond basic nutrition.

Consumers are becoming more aware of their health and well-being and the important role that healthy eating can potentially play in improving a range of health conditions. These include weight control, diabetes, cardiovascular health, digestive health, joint health, cognitive function, immune function and anti-ageing. Energy foods and beverages are also of increasing interest for sports nutrition.

Examples of components of interest to the nutraceutical and food industries are given in Table 1 (*below*). Oil and oil-soluble bioactive ingredients, such as omega-3 fatty acids, carotenoids and vitamins A and D, are being increasingly incorporated into food products for their potential health benefits (*see Table 2, following page*).

There are many estimates of the size of the nutraceuticals, supplements and functional food markets, depending on how the market is segmented. The global nutraceutical food market, beverage market and nutraceutical market for 2011 was estimated to be US$49bn, US$57bn and US$151bn respectively (www.bccresearch.com).

Bioactive components need to be delivered and released at their target site for optimal health benefits and encapsulation offers one solution to this.

Adding and delivering bioactives

When adding bioactive ingredients to food, there are several issues to consider. Many food bioactives are unstable once they are isolated from their natural source and require protection throughout their shelf-life, as an ingredient and in fortified food products, without compromising the sensory properties of the food.

Bioactives need to be protected before their ▶

TABLE 1: EXAMPLES OF CLASSES OF COMPONENTS OF INTEREST TO THE NUTRACEUTICALS/SUPPLEMENTS AND FOOD INDUSTRIES

Class	Examples
Phytochemicals	Beta-carotene, lycopene, lutein, co-enzyme Q_{10}, polyphenols
Minerals	Calcium, iron, chromium, zinc
Vitamins	Water-soluble vitamins (Vitamins B, C) Fat-soluble vitamins (Vitamins A, D, E, K)
Herbs/botanicals	Green tea, guarana, essential oils, spices
Proteins and peptides	Dairy-based protein hydrolysates, soya-based protein hydrolysates
Probiotics	Lactobacilli, bifidobacterium
Prebiotics	Oligosaccharides, inulin, plant-based fibres

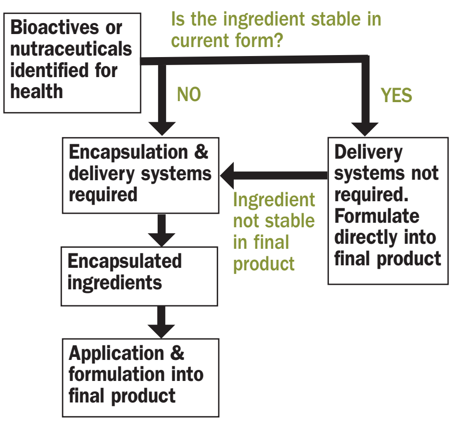
TABLE 2: SELECTED EXAMPLES OF OIL AND OIL-SOLUBLE BIOACTIVES AND THEIR POTENTIAL HEALTH BENEFITS

Bioactive	Examples	Potential health benefits
Fatty acids & oils	Omega-3 fatty acids, fish oil, algal oil Butyric acid	Cardiovascular, brain and eye health Gut health
Carotenoids	Beta-carotene, lycopene, lutein, zeaxanthin	Macular degeneration, eye health, heart health
Oil-soluble antioxidants	Tocopherols, tocotrienols	Cardiovascular health, protective against cancer
Phytosterols	Stigmasterol, beta-sitosterol, campesterol	Cardiovascular health
Oil-soluble vitamins	Vitamins A,D	Eye health, bone health
Phytonutrient	Coenzyme Q_{10}	Heart health, protective against cancer

TABLE 3: FOOD-GRADE MATERIALS USED FOR ENCAPSULATION OF FOOD BIOACTIVES

Material class	Types of materials
Proteins	Milk proteins – caseins and whey proteins Soya proteins Wheat proteins Egg proteins Zein Hydrolysed protein
Polysaccharides	Starch and starch products – maltodextrins, dextrins, starches, resistant starch, modified starches Gums – agar, alginates, carrageenan, gum acacia, gum arabic, pectin, carboxymethyl cellulose Chitosan
Lipids	Natural fats and oils Fractionated fats Mono- and di-glycerides Phospholipids Glycolipids Waxes – beeswax, carnauba wax
Note: Only food grade materials are allowed for food applications	

FIGURE 1: ISSUES TO CONSIDER WHEN ASSESSING THE NEED FOR ENCAPSULATION TO DELIVER A BIOACTIVE



Source: Augustin, M.A. & L. Sanguansri. 2012. Challenges in developing delivery systems for food additives, nutraceuticals and dietary supplements. In "Encapsulation Technologies and Delivery Systems for Food Ingredients and Nutraceuticals", Eds. Garti & McClements, Woodhead Publishing, Cambridge, UK. Pp 19-48).

release at the desired site in the body. There are therefore stringent demands for delivery systems for bioactives intended for food applications.

The bioactive ingredient should:

- Be added at an appropriate level.
- Be stable for the duration of storage of the ingredient.
- Be sufficiently stable during processing.
- Be stable during the shelf-life of the final food into which it is incorporated.
- Not have undesirable interactions with other food components.
- Not impart undesirable characteristics to the food.
- Be bio-available when ingested.
- Be delivered to the particular target site within the body to exert the desired physiological function.
- Be incorporated into food targeted at the population at risk.
- Have validation of their physiological effects.

All these demands cannot usually be met by direct addition of a bioactive to food. Nano- and micro-encapsulation offer a solution although several questions need to be asked before going down the route of encapsulation.

Nano- and micro-encapsulation

Nano- and micro-encapsulation can be described as the science of packaging components within a secondary material and delivering them in small particles (in the nanometer to micrometer range).

The bioactive is protected from interactions during food processing and storage and the loss of bioactivity is reduced. The taste and odour of bioactives may be masked if required. Encapsulation offers the potential for targeted delivery in the body.

The first question that needs to be considered is whether or not encapsulation is required for the successful delivery of a bioactive ingredient (*see Figure 1, below*).

The main purpose of encapsulation is to produce particles that control mass transport behaviour. The shell material prevents diffusion of the material from the microcapsule or into it. The wall material (encapsulant) protects the sensitive bioactive agent (core) from the environment (such as oxygen, water and light) until it is released at a desired time /site.

When appropriately formulated, the nano-/micro-capsules are stable during storage as an ingredient and through processing into the final food. When the trigger event for the release of the core occurs, the bioactive core is released into the surrounding environment. The release is governed by how the encapsulating material responds to a trigger (such as pH, temperature, shear, moisture or digestive enzymes).

As an example, in a target delivery to the gastrointestinal tract, there are different sites of delivery desired for various health outcomes. For inflammatory gut diseases, the target site may be the distal small intestine or the colon. The challenge, depending on the target release site, may be protection against stomach acid and enzymes and protection against enzymes in the small intestine such as amylases, proteases and lipases if release in the colon is targeted.

When the encapsulated bioactive is intended for incorporation into foods, the materials used for encapsulation of food bioactives need to be food grade. Hence encapsulating materials commonly used include proteins, polysaccharides lipids and allowed food additives (*see Table 3, above*). The methods used for encapsulation include both physical and chemical processes (*see Table 4, following page*)

Considerations for design include properties of the bioactive (core component), encapsulant material and the microcapsule (*see Table 5, following page*).

Oil and oil-soluble ingredients

There are difficulties in using an oxidatively unstable oil ingredient such as fish oil in processing and a powder ingredient is the preferred choice, as it is more convenient to transport and use than neat oil.

Micro-encapsulation enables the conversion of a liquid oil into a formulated emulsion which can then be dried to produce a powder (*see photo, below right*). It offers the potential to mask the fishy taste, and enhance stability and ease of use of fish oil for incorporation into foods. Using omega-3 oils as an example, the major issues and challenges for incorporating this sensitive bioactive include a fishy taste and odour potentially occurring in the end product. The unsaturated fatty acid needs to be stabilised and protected to prevent development of rancid flavours. The omega-3 oils need to be isolated from its surrounding environment to prevent interactions with other ingredients.

MicroMAX is the micro-encapsulation technology platform of Australia's national science agency, CSIRO (Commonwealth Scientific and Industrial Research Organisation). MicroMAX technology uses natural food grade materials and simple chemistry, without additives, utilising standard food processing equipment.

The encapsulant material in MicroMAX is comprised of protein-carbohydrate conjugates (Maillard reaction products). This offers good emulsifying properties, resulting in high oil loading in fish oil powders. The encapsulant material forms robust films around oxygen-sensitive oil droplets, and a protective barrier for bioactives against the environment during storage of the ingredient and the processing of the final food product into which it is incorporated. The MicroMAX encapsulant is a novel encapsulant material with improved antioxidant and film-forming properties.

Omega-3 oil powders can be produced using food materials only (proteins and carbohydrates). The encapsulant material and fish oil are emulsified to produce a stabilised liquid emulsion which is spray dried, resulting in a spray-dried emulsion (powder). Fish oil powders produced using MicroMAX technology can have higher oil loading and a longer shelf life than powders based on competing technologies (*see Figure 2, above*).

Food products containing micro-encapsulated omega-3 oils include infant formula, bread, smoothies, fish fingers, processed meat, flour and tinned spaghetti. In tests with ileostomy[1] patients, it has been shown that the delivery of fish oil in microcapsules within a range of food matrices does not compromise bioavailability of the oil[2].

Many encapsulation systems have been examined for oil and oil soluble bioactives. MicroMAX has the potential to be used as alternative encapsulating material for a range of oil soluble bioactives.

Conclusion

In conclusion, the food industry is experiencing growing demand for healthy bioactive ingredients. The incorporation of bioactives remains a significant challenge for many such agents isolated from their natural source. Micro-encapsulation provides a solution for delivery of bioactives into foods. The oils and bioactive components need to be released at target sites for optimal health benefit.

The encapsulant formulation and its structure, as well as food microstructure, can affect the bioavailability of micro-encapsulated oil/oil soluble bioactives. If microcapsules are incorporated into foods, there is a need to establish release properties with the food vehicle used. Further research is also required for confirmation of bio-efficacy for target health conditions. ●

[1] *An ileostomy is an opening in the belly (abdominal wall) that is made during surgery. The end of the ileum (the lowest part of the small intestine) is brought through this opening to form a stoma. As part of this surgery, the colon and rectum are often removed, meaning that digestive contents now leave the body through the stoma.*

[2] *Sanguansri L, Shen Z, Weerakkody R, Barnes M, Lockett T and Augustin MA (2013) Food & Function, 4, 74-82*

This feature is based on a paper presented by Mary Ann Augustin (Research Program Leader) & Luz Sanguansri (Research Team Leader, Micro-encapsulation), CSIRO Animal, Food and Health Sciences, Australia at OFIC 2012, held from 12-14 September in Malaysia

FIGURE 2: COMPARISON OF SHELF-LIFE OF FISH OIL POWDERS MADE USING MICROMAX TECHNOLOGY COMPARED TO USING A PHYSICAL (PROTEIN-CARBOHYDRATE) BLEND AS ENCAPSULATING MATERIALS

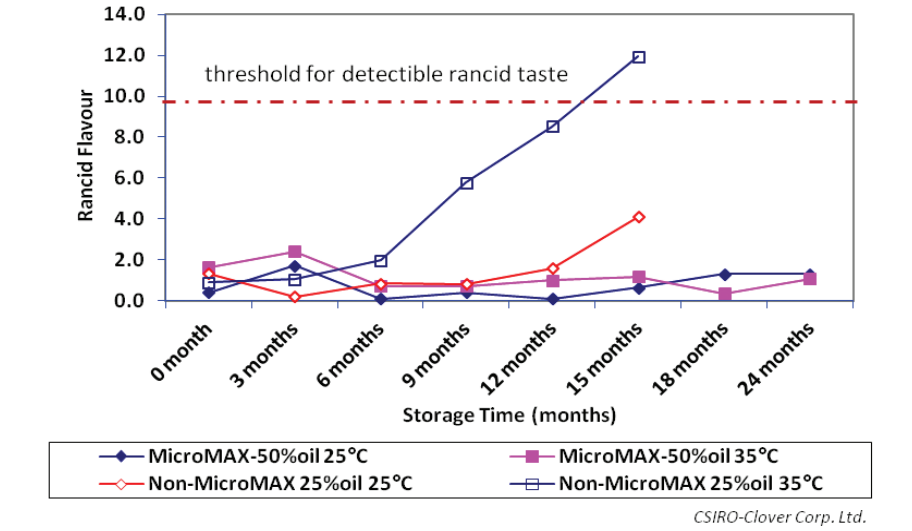


TABLE 4: PROCESSES USED FOR ENCAPSULATION

Physical	Chemical
Spray drying (of emulsions)	Simple coacervation
Spray chilling	Complex coacervation
Coating – fluidised bed, spinning disk	Solvent evaporation
Extrusion – centrifugal, pressure	Liposomes
Gelation	Chemical adsorbents
Emulsion formation	Inclusion complexation

LIQUID OIL AND MICRO-ENCAPSULATED SPRAY-DRIED OIL EMULSIONS

TABLE 5: CONSIDERATIONS IN THE DESIGN OF ENCAPSULATED BIOACTIVES

Component	Properties
Core	Bioactivity of the material Solubility (hydrophilicity/ lipophilicity Taste Stability
Encapsulant material	Solubility Viscosity Stability Film forming/emulsification properties Regulatory status for food application
Microcapsule	Format for delivery (liquid/powder) Particle size Payload (bioactive core loading) Storage stability Stability to different process conditions Release properties Cost of production