Functional Food Product Development

Edited by

Jim Smith and Edward Charter
Prince Edward Island Food Technology Centre
Charlottetown, Canada
Functional Food Product Development
Functional Food Science and Technology Series

Functional foods resemble traditional foods but are designed to confer physiological benefits beyond their nutritional function. Sources, ingredients, product development, processing and international regulatory issues are among the topics addressed in Wiley-Blackwell’s new Functional Food Science and Technology book series. Coverage extends to the improvement of traditional foods by cultivation, biotechnological and other means, including novel physical fortification techniques and delivery systems such as nanotechnology. Extraction, isolation, identification and application of bioactives from food and food processing by-products are among other subjects considered for inclusion in the series.

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Functional Food Product Development

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Preface

According to an August 2009 report from PricewaterhouseCoopers, the US market for functional foods in 2007 was US$27 billion. Forecasts of growth range between 8.5 and 20% per year or about four times that of the food industry in general. Global demand by 2013 is expected to be about US$100 billion. With this demand for new products comes a demand for product development and supporting literature for that purpose. There is a wealth of research and development going on in this area and much opportunity for commercialisation. This book provides a much-needed review of important opportunities for new products from many perspectives including those with in-depth knowledge of as yet unfulfilled health-related needs.

This book addresses functional food product development from a number of perspectives: the process itself, health research that may provide opportunities, idea creation, regulation; and processes and ingredients. It also features case studies that illustrate real product development and commercialisation histories. Written for food scientists and technologists, and scientists working in related fields, the book presents practical information for use in functional food companies and food technology centres and will also be of interest to researchers and students of food science.


Within the text of the book, there are suggestions, ideas and clues for new functional food products; some are more obvious than others and some are closer to commercialisation than others, but numerous new products could result from the information contained herein. There is a large, growing market for unique functional food products that provide proven health benefits to consumers, and we hope that this book will play an important role in the creation of those products.

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Part I

New technologies for functional food manufacture
1 Microencapsulation in functional food product development

Luz Sanguansri and Mary Ann Augustin

1.1 Introduction

Functional foods provide health benefits over and above normal nutrition. Functional foods are different from medical foods and dietary supplements, but they may overlap with those foods developed for special dietary uses and fortified foods. They are one of the fastest growing sectors of the food industry due to increasing demand from consumers for foods that promote health and well-being (Mollet & Lacroix 2007). The global functional food market, which has the potential to mitigate disease, promote health and reduce health care costs, is expected to rise to a value of US$167 billion by 2010, equating to a 5% share of total food expenditure in the developed world (Draguhn 2007).

Functional foods must generally be made available to consumers in forms that are consumed within the usual daily dietary pattern of the target population group. Consumers expect functional foods to have good organoleptic qualities (e.g. good aroma, taste, texture and visual aspects) and to be of similar qualities to the traditional foods in the market (Klont 1999; Augustin 2001; Kwak & Jukes 2001; Klahorst 2006). The demand for bioactive ingredients will continue to grow as the global market for functional foods and preventative or protective foods with associated health claims continues to rise. Over the last decade, there has been significant research and development in the areas of bioactive discovery and development of new materials, processes, ingredients and products that can contribute to the development of functional foods for improving the health of the general population.

New functional food products launched in the global food and drinks market have followed the route of fortification or addition of desirable nutrients and bioactives including vitamins, minerals, antioxidants, omega-3 fatty acids, plant extracts, prebiotics and probiotics, and fibre enrichments. Many of these ingredients are prone to degradation and/or can interact with other components in the food matrix, leading to loss in quality of the functional food products. To overcome problems associated with fortification, the added bioactive ingredient should be isolated from environments that promote degradation or undesirable interactions. This may be accomplished by the use of microencapsulation where the sensitive bioactive is packaged within a secondary material for delivery into food products. This chapter covers the microencapsulation of food components for use in functional food product formulations and how these components can be utilised to develop commercially successful functional foods.
1.2 Microencapsulation

Microencapsulation is a process by which a core, i.e. bioactive or functional ingredient, is packaged within a secondary material to form a microcapsule. The secondary material, known as the encapsulant, matrix or shell, forms a protective coating or matrix around the core, isolating it from its surrounding environment until its release is triggered by changes in its environment. This avoids undesirable interactions of the bioactive with other food components or chemical reactions that can lead to degradation of the bioactive, with the possible undesirable consequences on taste and odour as well as negative health effects.

It is essential to design a microencapsulated ingredient with its end use in mind. This requires knowledge of (1) the core, (2) the encapsulant materials, (3) interactions between the core, matrix and the environment, (4) the stability of the microencapsulated ingredient in storage and when incorporated into the food matrix and (5) the mechanisms that control the release of the core. Table 1.1 gives examples of cores that have been microencapsulated for use in functional food applications. The molecular structure of the core is usually known. However, information is sometimes lacking on how the core interacts with other food components, its fate upon consumption, its target site for action and in the case of a bioactive core, sometimes its function in the body after ingestion may also be unclear (de Vos et al. 2006).

1.2.1 Encapsulant materials

Depending on the properties of the core to be encapsulated and the purpose of microencapsulation, encapsulant materials are generally selected from a range of proteins, carbohydrates, lipids and waxes (Table 1.2), which may be used alone or in combination. The materials chosen as encapsulants are typically film forming, pliable, odourless, tasteless and non-hygroscopic. Solubility in aqueous media or solvent and/or ability to exhibit a phase transition, such as melting or gelling, are sometimes desirable, depending on the processing requirements for production of the microencapsulated ingredient and for when it is incorporated into the food product. Other additives, such as emulsifiers, plasticisers or defoaming agents, are sometimes included in the formulation to tune the final product’s characteristics. The encapsulant material may also be modified by physical or chemical means in order to achieve the desired functionality of the microencapsulation matrix. The choice of encapsulant material is therefore dependent on a number of factors, including its physical and chemical
Table 1.2: Materials that have been used as encapsulants for food application

<table>
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<tr>
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<th>Carbohydrates</th>
<th>Proteins</th>
<th>Lipids and waxes</th>
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<td>Sodium caseinate</td>
<td>Vegetable fats and oils</td>
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<tr>
<td>Modified starches</td>
<td>Whey proteins</td>
<td>Hydrogenated fats</td>
<td></td>
</tr>
<tr>
<td>Resistant starches</td>
<td>Isolated wheat proteins</td>
<td>Palm stearin</td>
<td></td>
</tr>
<tr>
<td>Maltodextrins</td>
<td>Soy proteins</td>
<td>Carnauba wax</td>
<td></td>
</tr>
<tr>
<td>Dried glucose syrups</td>
<td>Gelatins</td>
<td>Bees wax</td>
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<tr>
<td>Gum acacia</td>
<td>Zein</td>
<td>Shellac</td>
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<tr>
<td>Alginates</td>
<td>Albumin</td>
<td>Polyethylene glycol</td>
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<td>Pectins</td>
<td>Carageenan</td>
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<td>Chitosan</td>
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<td>Cellulosic materials</td>
<td>Sugars and derivatives</td>
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properties, its compatibility with the target food application and its influence on the sensory and aesthetic properties of the final food product (Brazel 1999; Gibbs et al. 1999).

The ability of carbohydrates to form gels and glassy matrices has been exploited for microencapsulation of bioactives (Reineccius 1991; Kebyon 1995). Starch and starch derivatives have been extensively used for the delivery of sensitive ingredients through food (Shimoni 2008). Chemical modification has made a number of starches more suitable as encapsulants for oils by increasing their lipophilicity and improving their emulsifying properties. Starch that was hydrophobically modified by octenyl succinate anhydride had improved emulsification properties compared to the native starch (Bhosale & Singhal 2006; Nilsson & Bergenstahl 2007). Acid modification of tapioca starch has been shown to improve its encapsulation properties for β-carotene, compared to native starch or maltodextrin (Loksuwan 2007). Physical modification of starches by heat, shear and pressure has also been explored to alter its properties (Augustin et al. 2008), and the modified starch has been used in combination with proteins for microencapsulation of oils (Chung et al. 2008).

Carbohydrates used for microencapsulation of β-carotene, from sea buckthorn juice, by ionotropic gelation using furcellaran beads, achieved encapsulation efficiency of 97% (Laos et al. 2007). Interest in using cyclodextrins and cyclodextrin complexes for molecular encapsulation of lipophilic bioactive cores is ongoing, especially in applications where other traditional materials do not perform well, or where the final application can bear the cost of this expensive material. The majority of commercial applications for cyclodextrins have been for flavour encapsulation and packaging films (Szente & Szejtli 2004).

Proteins are used as encapsulants because of their excellent solubility in water, good gel-forming, film-forming and emulsifying properties (Kim & Moore 1995; Hogan et al. 2001). Protein-based microcapsules can be easily rehydrated or solubilised in water, which often results in immediate release of the core. Proteins are often combined with carbohydrates for microencapsulation of oils and oil-soluble components. In the manufacture of encapsulated oil powders, encapsulation efficiency was higher when the encapsulation matrix was a mixture of milk proteins and carbohydrates, compared to when protein was used alone (Young et al. 1993). Soy protein-based microcapsules of fish oil have been cross-linked using transglutaminase to improve the stability of the encapsulated fish oil (Cho et al. 2003). Protein-based hydrogels are also useful as nutraceutical delivery systems (Chen et al. 2006).
The release properties of protein-based hydrogels and emulsions may be modulated by coating the gelled particles with carbohydrates. A model-sensitive core, paprika oleoresin, was encapsulated in microspheres of whey proteins and coated with calcium alginate to modify the core's release properties (Rosenberg & Lee 2004). Whey protein-based hydrogels with an alginate coating altered the swelling properties of the gelled particles. The stability of these particles was increased at neutral and acidic conditions both in the presence and absence of proteolytic enzymes (Gunasekaran et al. 2007).

Lipids are generally used as secondary coating materials applied to primary microcapsules or to powdered bioactive cores to improve their moisture barrier properties (Wu et al. 2000). Lipids can also be incorporated in an emulsion formulation to form a matrix or film around the bioactive core (Crittenden et al. 2006).

The increasing demand for food-grade materials that will perform under the different stresses encountered during food processing has spurred the development of new encapsulant materials. Understanding the glass transition temperature of various polymers (e.g., proteins and carbohydrates) and their mixtures is also becoming important as this can influence the stability of the encapsulated core. The low water mobility and slow oxygen diffusion rates in glassy matrices can improve stability of bioactives (Porzio 2003). It is possible to exploit thermally induced interactions between proteins and polysaccharides and then to use the modified materials for encapsulation. Hydrogels formed by heat treatment of β-lactoglobulin–chitosan have been investigated, and it has been suggested that under controlled conditions these complexes may be useful for microencapsulation of functional food components (Hong & McClements 2007). Maillard reaction products formed by interactions between milk proteins and sugars or polysaccharides have been used as encapsulating matrices to protect sensitive oils and bioactive ingredients (Sanguansri & Augustin 2001).

### 1.2.2 Microencapsulation processes

Microencapsulation processes traditionally used to produce a range of microencapsulated food ingredients are listed in Table 1.3. A number of reviews give further details on microencapsulation technology in the food industry (Augustin et al. 2001; Gouin 2004). The choice of method used for microencapsulation depends on the properties of the core, the encapsulant materials and the requirements of the target food application. Figure 1.1 shows the structure of microencapsulated oil produced using three different microencapsulation processes.

Methods used for microencapsulation in the food industry have generally been adapted from technologies originally developed for the pharmaceutical industry. Mechanical processes use commercially available equipment to create and stabilise the microcapsules,

<table>
<thead>
<tr>
<th>Mechanical processes</th>
<th>Chemical processes</th>
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<tbody>
<tr>
<td>Emulsification</td>
<td>Ionotropic gelation</td>
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<tr>
<td>Spray-drying</td>
<td>Simple coacervation</td>
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<tr>
<td>Fluidised-bed coating</td>
<td>Complex coacervation</td>
</tr>
<tr>
<td>Centrifugal extrusion</td>
<td>Solvent evaporation</td>
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<tr>
<td>Spinning disk</td>
<td>Liposomes</td>
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<tr>
<td>Pressure extrusion</td>
<td>Cyclodextrin complexation</td>
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<tr>
<td>Hot-melt extrusion</td>
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Fig. 1.1 Structure of microencapsulated oil produced using different microencapsulation processes.
whereas chemical processes capitalise on the possible interactions that can be promoted by varying the process conditions used to create the microcapsules.

Spray-drying is the most commonly used mechanical method for microencapsulation of bioactive food ingredients. Gharsallaoui et al. (2007) reviewed the use of spray-drying for the microencapsulation of food ingredients. It is efficient and cost-effective and uses unit processes and equipment readily available in most food processing plants. Spray-dried ingredients have reasonably good powder characteristics and good stability. Fluidised-bed coating is another mechanical process used for encapsulation of dry bioactive cores and ingredients. It consists of spraying an aqueous or solvent-based liquid coat onto the particles followed by drying. Dry particle coating of bioactive cores is an adaptation of the fluidised-bed coating technique that has been investigated by Ivanova et al. (2005) for microencapsulation of water-sensitive ingredients. The dry particle coating method avoids the use of aqueous or solvent-based coatings.

Of the different chemical microencapsulation processes available, only gelation and coacervation are widely used in the food industry. All current chemical methods are batch processes, although there is significant effort going into the development of continuous processes. Biopolymer–biopolymer supramolecular structures as complexes and coacervates may be formed under conditions where the two biopolymers carry opposite charges. These structures may have potential for controlled release and delivery of bioactives in foods (Turgeon et al. 2007; Livney 2008). The formation of native whey protein isolate-low methoxy pectin complexes by electrostatic interaction has potential for entrapment of water-soluble ingredients in acidic foods, as demonstrated by the entrapment of thiamine by Bedie et al. (2008).

Liquid emulsions may also be used as delivery systems in foods (Appelqvist et al. 2007; McClements et al. 2007). Oil-in-water emulsions are suitable for the delivery of lipids and lipid-soluble bioactives. Kinetically stable oil-in-water emulsions are made by homogenising a mixture of either an oil or an oil containing a lipid-soluble bioactive, with an aqueous solution containing the encapsulating material. Spontaneously formed, thermodynamically stable microemulsions may also be loaded with nutraceuticals and used as delivery systems. Garti and Amar (2008) have discussed the importance of understanding the nature of the microstructures and phase transitions in micro- and nanoemulsions for the effective delivery of nutraceuticals. Leal-Calderon et al. (2007) highlighted the need to understand the formulation and the design and characterisation of structured emulsions in order to control the release of bioactives in foods when ingested. Guzey and McClements (2006) explored ways of improving the release characteristics of conventional primary emulsions for controlled or triggered release delivery systems of bioactives, by developing multilayered emulsion formulations. Preparation of water-in-oil-in-water (w/o/w) emulsions by membrane filtration was explored by Shima et al. (2004) to encapsulate a model hydrophilic bioactive, with a view to protecting functional food ingredients for controlled release application.

**1.2.3 Drivers for microencapsulation**

The primary reasons for microencapsulation of food ingredient are to (1) protect the core from degradation during processing and storage, (2) facilitate or improve handling during the production processes of the final food application and (3) control release characteristics of the core, including its delivery to the desired site after ingestion.

Many bioactives (e.g. omega-3 oils, carotenes and polyphenols) need to be protected against degradation. For example, omega-3 oils are very susceptible to oxidation, leading to
the development of off-flavours and off-odours. Microencapsulation protects the sensitive oils from exposure to oxygen, light and metal ions during processing and storage (Sanguansri & Augustin 2006). Protecting the core from degradation and from interactions with other food components can extend the shelf stability of the ingredient itself, as well as that of the final food product to which it is added.

Microencapsulation can facilitate or improve handling of ingredients during production processes used in the final applications. The conversion of a liquid ingredient into a powder offers significant convenience, as it is much easier to store, weigh and add a powdered ingredient, compared to its liquid version. Microencapsulation can aid in the addition and more uniform blending of bioactive ingredients into a food formulation. Bioactive ingredients in their pure or very concentrated forms are usually added in very low amounts (sometimes at ppm levels). Addition of a few milligrams or grams of ingredients into hundreds of kilos or tonnes of products can lead to uneven distribution within the food matrix, especially when ingredients are dry-blended. Microencapsulated forms with much lower payload can be used in these applications to facilitate a more homogeneous blending of these highly potent bioactive ingredients into food because the lower payloads provide a larger amount of the microencapsulated ingredient to be added to the mix into which it has to be blended.

Bioactive ingredients may require microencapsulation to improve or modify their functionality and release characteristics. Understanding the core, the final application, and the mechanism required to release the core is essential for effective design of the microcapsule’s release characteristics. Different release characteristics can be achieved depending on the requirement, e.g. controlled, sustained or delayed release. Bioactive ingredients are often known to possess undesirable tastes and/or odours that require masking before they can be used successfully in food formulations. A significant challenge associated with nutraceutical ingredients is the need to mask bitterness and aftertaste (Anon 2006). With new developments in understanding the science of taste, the introduction of new bitterness blockers and sweetness potentiators in food formulations (McGregor 2004) can be combined within a microencapsulation system to allow controlled, delayed or sustained release of bioactives.

During the addition of bioactive ingredients into food, it is essential that both the bioactivity and the bioavailability are maintained to ensure that the bioactives achieve the desired function in the body. When direct addition of the bioactive could compromise its bioavailability, it needs to be protected by microencapsulation. The protection of the core from the acidic pH of the stomach during transit through the gastrointestinal (GI) tract may potentially enable more efficient delivery of the bioactive to the target site in the body and may also reduce the dosage required to achieve the health benefits.

Advances in the development of microencapsulation technology for food applications have been driven by the need for (1) the core to be encapsulated, (2) new and alternative materials that are cost-effective encapsulants and (3) materials which will withstand the processes widely used in the food industry. More recent developments in microencapsulation technologies for food applications have focused on applying the technology to more cost-effective food-grade encapsulant materials and processes available in the food industry. The need for controlled release and delivery of bioactive food ingredients to target sites in the body continues to drive other new developments. Converting stable microcapsule formulations (emulsions, dispersions, suspensions, coacervates) into powders is still the preferred option for production of microencapsulated bioactive ingredients, as it offers more convenience and flexibility. An understanding of how these formulations will behave during the drying process and on reconstitution is critical to the success of powdered preparations.
With the primary reason or purpose of microencapsulation being clearly identified, other important factors need to be seriously considered to ensure proper selection of encapsulant materials and processes that are cost-effective, practical and scalable. Important considerations during the development of microencapsulated products include (1) core properties – e.g. chemical structure, solubility and stability, (2) product format – e.g. liquid or powder format depending on final application, (3) physical properties of the microencapsulated ingredient – e.g. particle size, bulk density and colour, (4) payload – i.e. amount of bioactive loading in the microcapsule, (5) release trigger mechanism – e.g. dissolution, pressure, heat and shear, (6) storage conditions and shelf-life requirements – e.g. refrigerated or ambient storage and (7) legal and regulatory requirements for addition into food in the country of its application. From a commercial perspective, there is the additional factor of material and production costs and whether the final food product can bear the additional cost of using a microencapsulated ingredient.

1.3 Microencapsulated food ingredients

There are several technical challenges in developing functional ingredients for incorporation into foods. They must satisfy the sensory demands of the consumers and ensure that the bioactive can be delivered to specific sites in the GI tract to exert the desired health benefit. Microencapsulation has been applied to a number of food ingredients to develop them into tailor-made bioactive ingredients (Augustin & Sanguansri 2008).

The increasing number of microencapsulated food ingredient launches has been the result of more creative translation and adaptation of microencapsulation techniques originally developed in the pharmaceutical industries. New encapsulant materials and more cost-effective formulations and processes have enabled the food industry to develop these new ingredients with added value and functionality. In more recent years, the addition of microencapsulated ingredients into a wider range of food products ensures that it does not significantly affect the cost of the final food product. This is a significant issue as food has very low profit margins compared to pharmaceuticals.

1.3.1 Vitamins and minerals

Fortification with vitamins and minerals is often challenging due to their susceptibility to degrade during processing and storage and to react with other components in the food system. Vitamins and minerals are generally sensitive to temperature, moisture, light and pH, and their potency is often compromised by their reaction with other ingredients or premature release.

Vitamins and minerals are added to a range of food products for the following reasons: (1) to replace those that are lost during processing and storage; (2) to meet special nutritional needs, e.g. for infants and elderly; and (3) to prevent disease in specific consumer or at-risk groups. Traditionally, higher levels than that are required in the end product have been added to overcome losses during processing and storage. These high overages may be avoided by using microencapsulated forms.

For water-soluble vitamins (e.g. vitamins B and C) and minerals (e.g. iron and calcium), spray-drying, spray chilling, fluidised-bed coating and spinning disk coating have been used to manufacture dry powder microcapsules. Where liquid microcapsule formats are
preferred, microencapsulation in liposomal delivery systems can be used. There is also the possibility of entrapping water-soluble vitamins in double emulsions. Fechner et al. (2007) demonstrated that vitamin B12 in the inner phase of an oil/water/oil emulsion stabilised by caseinate–dextran conjugates, instead of pure protein, reduced the release of the vitamin under acidic conditions. For lipid-soluble vitamins (e.g. vitamins A, D, E and K) and provitamin A (β-carotene), stable emulsion formulations or spray-dried emulsions are commonly used as delivery systems. Emulsion-based systems are often used for delivery of lipid-soluble bioactives (McClements et al. 2007). However, where there are specific interactions between hydrophobic bioactives and a protein, an aqueous-based system may be exploited. Semo et al. (2007) demonstrated that casein micelles were useful for delivery of vitamin D2.

Microencapsulation has benefits when used for delivery of iron and calcium in foods. Direct addition of iron into foods may reduce its bioavailability through interaction with tannins, phytates and polyphenols. Free iron is also known to catalyse the oxidation of fats, vitamins and amino acids. These interactions can affect the sensory characteristics of the final food formulation, as well as decrease the nutritional value of the food due to iron-induced catalysis of deteriorative reactions. Many of these limitations of direct addition of iron may be overcome by microencapsulation. Other microencapsulation technologies used for encapsulation of iron include liposomal delivery systems and application of lipid coats by fluidised-bed coating (Xia & Xu 2005). Molecular inclusion of iron using cyclodextrins may also be used in its delivery (Leite et al. 2003).

The interaction of calcium with proteins can cause unwanted coagulation or precipitation of the protein, especially in calcium-fortified protein beverages. Calcium is naturally present in dairy products, but there is interest in fortifying other protein products with calcium, such as soy protein beverages. Calcium fortification of protein-based beverages may be achieved with the addition of calcium-chelating agents; however, this may result in an undesirable taste when high levels of calcium fortification are desired. Microencapsulation of calcium can prevent its negative interaction with other food components (e.g. soy proteins) in the food environment. A liposomal delivery system has also been examined for this application (Hirotsuka et al. 1984).

1.3.2 Functional fatty acids

Functional fatty acids, particularly docosahexaenoic acid, eicosapentaenoic acid, α-linolenic acid and conjugated linoleic acid, have attracted significant attention due to their potential health benefits (Ohr 2005). Emulsion-based technologies and spray-drying are currently the most common approaches employed for microencapsulation and delivery of functional fatty acids into food (Sanguansri & Augustin 2001; McClements et al. 2007).

Omega-3 fatty acids are highly susceptible to oxidation and have an inherent fishy taste and odour. Therefore, most food applications of omega-3 fatty acids require microencapsulation for protection from oxidation and to mask the fishy taste and odour. Significant research has been carried out on microencapsulation of omega-3 fatty acids. An increasing number of food companies are developing new functional food products containing omega-3 fatty acids. This increase in the number of food products launched containing omega-3 fatty acids has also been driven by the qualified health claims that were allowed by Food and Drug Administration (FDA) in 2004. Technologies that have been successfully used to encapsulate omega-3 oils include emulsification and spray-drying (Sanguansri & Augustin 2001), coacervation (Wu et al. 2005), cyclodextrin complexation and liposomal preparations (Tanouchi et al. 2007).
1.3.3 Probiotics

Probiotics are live microorganisms that must remain alive during processing, storage and gastric transit to fulfil their desired function in the body (Mattila-Sandholm et al. 2002). Much clinical data have been accumulated to support the role of probiotics in human health by benefiting the immune system, strengthening the mucosal barrier and suppressing intestinal infection (Saarela et al. 2002). This has driven interest in adding probiotics to a wider range of food products, other than traditional fermented dairy products such as yoghurt. As probiotics are sensitive to heat and moisture, keeping them alive during food processing and storage is not easy. Even in fermented dairy product applications, the survival of probiotics during storage still remains a challenge for the industry.

Processes that have been used to encapsulate probiotics include spray coating, spray-drying, extrusion, emulsification and gel particle technologies. Of these technologies, the technique most widely investigated by researchers involves the use of polysaccharides to form gelled particles (Krassaekoopt et al. 2003; Anal & Singh 2007). However, the use of gelled particles for microencapsulation of probiotics has not been widely adopted by commercial companies, as it is a batch process. The use of alginate–chitosan microcapsules has also been explored to improve the mechanical strength of the capsules to survive in vitro digestion (Urbanska et al. 2007). The application of a lipid coating by a fluid-bed technique has also been used for probiotic encapsulation (Lee & Richardson 2004). Probiotics encapsulated in lipid-based materials are used, in a limited range of food products, with varying degrees of success. The application of high-melting-point lipids and waxes allows protection of probiotics from high-moisture environments and thermal protection below the melting point of the coat. Starch-based encapsulation was also explored by Lahtinen et al. (2007), but their results showed no effect on improving the viability of Bifidobacterium longum strains.

Spray-drying has always been an attractive process for production of powdered food ingredients because it is a continuous, high-volume and cost-effective process. A number of researchers have explored spray-drying for production of probiotic microcapsules with varying degrees of success (Desmond et al. 2002; Ananta et al. 2005; Anal & Singh 2007; Su et al. 2007). The most important step still remains the selection and formulation of an encapsulant that can protect the probiotics during drying. A novel microencapsulation technology using protein–carbohydrate conjugate in the matrix provided significant protection to probiotic bacteria during spray-drying, during exposure to acidic pH and during non-refrigerated storage at low to intermediate water activity (Crittenden et al. 2006). The use of appropriate materials and process conditions applied during microencapsulation has the potential to enable the addition of probiotics to a much wider range of food products with intermediate water activity which do not require refrigeration.

1.3.4 Phytochemicals

Phytochemicals are biologically active plant chemicals, with increasing evidence that they can reduce the risk of chronic diseases (Hasler 1998). Ingredients claimed to be rich in phytochemicals are extracted from plant sources. Once isolated from their natural environment, these bioactive ingredients generally require microencapsulation to stabilise the active component and mask undesirable tastes, colours and odours. The phytochemicals of interest to the food industry include phytosterols, tocopherols, carotenoids, coenzyme Q10, curcumin, garlic extracts and polyphenols (e.g. resveratrol).

Resveratrol is a naturally occurring non-flavonoid polyphenolic compound present in plants such as grapes, berries and peanuts (Halls & Yu 2008), as well as in cocoa and chocolate
Microencapsulation in functional food product development

(Counet et al. 2006). Resveratrol is photosensitive and benefits from microencapsulation to maintain its stability when added to food products. Shi et al. (2008) have shown that encapsulation of resveratrol in yeast cells can offer protection and enhance its stability as an ingredient. The use of chitosan–alginate coacervates as an encapsulant has also exhibited potential for preparation of encapsulated powder ingredients from aqueous (water-soluble) antioxidant plant extracts (Deladino et al. 2008).

The use of natural fruit fibres as encapsulating agents for the microencapsulation and spray-drying of sticky bioactive extracts (Hibiscus sabdariffa) has been explored by Chiou and Langrish (2007). Extracts containing curcumin have been encapsulated using commercially available lecithin to form liposomes by homogenisation or microfluidisation (Takahashi et al. 2007). The delivery of curcumin through oil-in-water nanoemulsions has been shown to enhance its anti-inflammatory activity in animal tests (Wang et al. 2008). Szente et al. (1998) demonstrated that the stability of curcumin and carotenoids is enhanced by molecular encapsulation using cyclodextrins.

1.3.5 Proteins, amino acids, peptides and enzymes

Proteins have traditionally been encapsulated for pharmaceutical applications (Putney 1998). The demand for more protein in food and beverages is on the rise (Sloan 2004). Whey, casein and soy proteins are commonly used in high-protein food formulations either in their native or hydrolysed forms.

Protein-derived peptides and amino acids are also being isolated from their source to enable addition at the correct dosage required for physiological health functions. The direct addition of these components into food and beverage formulations can result in an undesirable bitter taste and astringency. Encapsulation of casein hydrolysates in lipospheres has been found to reduce the bitterness (Barbosa et al. 2004).

Encapsulation may also be used to preserve the activity of enzymes. Components in garlic have also been shown to offer beneficial health effects (Gorinstein et al. 2007), and microencapsulation of garlic powder results in protection of alliinase activity, which improves the ratio of alliin to allicin conversion under in vitro conditions (Li et al. 2007).

1.3.6 Fibre

The trend of adding dietary fibres to food and beverage formulations that traditionally do not contain these fibres is increasing due to the increasing evidence of health benefits of high-fibre diets. Examples of dietary fibres for which the FDA has allowed health claims are β-glucan from oats and psyllium fibre. β-Glucan, a cholesterol-lowering soluble fibre, shown to reduce the risk of heart disease was allowed an FDA health claim in 1997. Later, in 1998, the FDA extended the health claim for soluble fibre to psyllium fibre. Other dietary fibres added to food and beverage formulations include indigestible gums, polysaccharides, oligosaccharides and lignins (Prosky 1999).

High levels of fibre need to be added in the final food formulation in order to make a health claim. The problems associated with the addition of high levels of dietary fibres to food and beverages are the unpalatability of the high-fibre ingredients and the significant effects they have on the viscosity of the final product. This has resulted in the development of expensive, refined fibre ingredients, e.g. polydextrose (Sunley 1998). Microencapsulation can minimise palatability problems as well as minimise water absorption during formulation and processing. Much cheaper sources (e.g. indigestible gums) can also be added at a much higher
levels if the fibre in food formulations is encapsulated with materials that can reduce hydration and water absorption during processing. Chito-oligosaccharide, as a functional ingredient, offers a range of health benefits; however, direct addition to milk can affect its flavour and colour. Microencapsulation of chito-oligosaccharide with polyglycerol monostearate, as explored by Choi et al. (2006), reduced its adverse effects on the physicochemical or sensory properties when added to milk.

1.4 Development of microencapsulated ingredients

1.4.1 The approach

During the development of functional foods using microencapsulated food ingredients, the selection of ingredients and processes was traditionally based on empirical approaches. Ubbink and Kruger (2006) have suggested that an alternative concept is to use a retro-design approach that relies more on a fundamental understanding of the required performance of the ingredient in a complex food environment. This approach encompasses an understanding of the effects of processing and the factors controlling the chemical and physical events that govern the stability and release properties of a microencapsulated product; however, the test of whether a microencapsulation system is suitably tailored for its end product application is its acceptance in the marketplace. The route from concept to acceptance of functional foods by consumers has many stages and requires input from scientists, technologists, nutritionists and an understanding of the regulatory processes (Jones & Jew 2007). Our own program of research in designing microencapsulated ingredients has utilised multidisciplinary expertise, involving chemistry, physics, food science and process engineering, with the regulatory and market requirements in mind to minimize or avoid issues during scale-up and commercialisation. This approach ensures that both the food and ingredient manufacturers’ requirements are met while consumers’ demands are also considered during the development. The final product application must be the focus of the microencapsulated product development in order that the core is protected from various stresses during incorporation into the final product. It is important to ensure that when microencapsulation is used to deliver active ingredients into foods, it provides a simple, efficient and cost-effective solution compared to direct addition of bioactives.

1.4.2 Product and process developments

Understanding the fundamental science of the core, as well as a good knowledge of the materials and processes available, is a requirement for the process of developing a successful product. The stages in the development of a microencapsulated product from bench scale product concept to a commercial product acceptable to consumers in final food applications are shown in Figure 1.2. In designing a cost-effective and tailor-made microcapsule suitable for its intended use (i.e. the final food product application), the final product format (liquid or dry) and the market (size and value) need to be identified at the outset. These factors will significantly influence the choice of materials, formulation and process that can be employed. At this stage, the physical performance and characteristics, core stability and possible interactions with other ingredients during formulation and process should be tested. A few iterations of changes to the initial formulation may be required until reasonable product