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Microencapsulation of Fish Oil : Application in Functional Food Development

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Introduction

Consumers' demand for healthy food products is increasing worldwide. Today foods are not intended only to satisfy hunger and provide necessary nutrients for humans. It also intended to prevent nutrition-related diseases and improve physical and mental well-being. In this regard, functional foods play an outstanding role. The foods that enriched with functional components to offer medical and physiological benefits to reduce the risk of chronic diseases beyond their basic nutritional functions are called as functional foods.

Fish oil is an excellent source of omega- 3 fatty acids especially EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid). Omega -3 fatty acids are found to have numerous benefits for human health which includes reduction of joint pain, prevention of rheumatoid arthritis, cancer, psoriasis, reduction of risk of coronary heart disease, vision improvement and brain developments (Adam et al., 2003). Many studies encourage the adequate intake of omega-3 fatty acids by pregnant and lactating women to support overall health and development of retina and brain in foetus. Omega-3 fatty acids content in seafood and fish oil are given in table-1.

The US Food and Drug Administration (FDA) has also recommended fish and algal oils for food fortification. Due to its unsaturated nature fish oils are susceptible to oxidation and it can be reduced by addition of antioxidant or preferably microencapsulation. Recently, micro-encapsulated fish oil has wide application in various food products which includes infant foods, health drink, milk-based products, juices, pastas, bakery products etc (Desai & Park, 2005; Jeyakumari *et al.,* 2016). Apart from these fish oils also marketed as capsule and powder form. Recommended level of EPA and DHA intake suggested by world health organization (WHO) and American Heart association is 0.7g/day.0.5-1.0g/day respectively. In addition to consumption of fish, intake of fish oil fortified food will meet the daily requirement of omega-3 fatty acids.

Microencapsulation : Microencapsulation is a process of coating of small particles of solid or liquid material (core) with protective coating material (matrix) to produce microcapsules in the micrometer to millimeter range. It is one of the methods of protecting sensitive substances and producing active ingredients with improved properties. The substance that is encapsulated may be called the core material, the active agent, internal phase, or payload phase. The substance that is encapsulating may be called the coating, membrane, shell, carrier material, wall material, external phase or matrix.

Microencapsulation Methods : The microcapsules are prepared by a variety of methods. The microencapsulation process can be divided in to physical and chemical process. Physical process includes spray drying, spray chilling, rotary disk atomization, fluid bed coating, stationary nozzle coextrusion, centrifugal head coextrusion, submerged nozzle coextrusion, and pan coating. Chemical process includes phase separation, solvent evaporation, solvent extraction, interfacial polymerization, simple, and complex coacervation and in situ polymerization (Zuidam & Heinrich, 2010)

Method used for microencapsulation of fish oil : The most commonly used commercial techniques for microencapsulation of fish oil are spray drying, freeze drying and complex coacervation. Emerging microencapsulation methods of fish oil includes spray granulation and fluid bed film coating, electrospraying and encapsulation using ultrasonic atomizer.

Spray-drying : It is widely used for the encapsulation of food additives, functional ingredients, and flavors. The major process involves dispersion of the substances to be encapsulated in a carrier material followed by atomization and dehydration of the atomized particles. During this process a film is formed at the droplet surface, there by retarding the larger active molecules while the smaller water molecules are evaporated. The particle size varied between 10 and 400 um. Morphology of encapsulates produced by this method are matrix type.

Freeze-drying/Lyophilization : It is one of the most useful processes for drying of thermo sensitive substances. The major steps involved in this process are (1) mixing of core in coating solution; (2) freeze-drying of the mixture; and (3) grinding (option). The particle size varies from 20 to 5000 μm. Morphology of encapsulates

Table-1 : Omega-3 fatty acid content in Seafood and Fish oil.

Seafood	Omega-3 (EPA + DHA) g/100 g	Fish oil	Fatty acid
Mackerel	1.8-5.3	Sardine oil	10 - 20% EPA
Salmon	1.0-2.0	Tuna oil	5 - 6% EPA
Trout	0.5-1.6	Mackerel oil	10 - 15% EPA
Tuna	0.5-1.6	Eel oil	8 - 12% EPA
Halibut	0.5-1.0	Salmon egg oil	15 - 30% EPA
Shrimp	0.2-0.4	Shark oil	20.6% EPA + DHA
Cod, plaice, flounder	~ 0.2	Cod liver oil	10% EPA + DHA

Adapted from Belda and Pourchet-Campos (1991) and Park et al. (1997).

Table-2 : Advantages and Disadvantages of various microencapsulation methods.

Methods	Advantage	Disadvantage
Spray drying	Simple method, fast and easy to scale-up, equipment is readily available; cost of spray-drying method is 30–50 times cheaper; both hydrophilic and hydrophobic polymer can be used; ideal for production of sterile materials.	considerable amounts of the material can be lost during the process due to sticking of the microparticles to the wall of the drying chamber; process variables that should be optimized for encapsulation
Spray Chilling or Spray Cooling	least expensive; active compounds released within a few minutes after being incorporated in the food stuff.	special handling and storage conditions can be required
Fluid bed coating	uniform layer of shell material onto solid particles; high thermal efficiency; lower capital and maintenance costs.	control of air stream and air temperature is a critical factor
Freeze drying	It is used for encapsulation of heat-sensitive materials and aromas; minimize the product oxidation.	high energy use, the long processing time, 30–50 times more expensive than Spray drying
Coacervation	It is used to encapsulation of polyphenols and water-soluble compounds.	mass production is difficult due to agglomeration
Liposome Entrapment	mainly studied for clinical application as pharmaceutical drug carriers	high cost, low stability and low encapsulation yield
Inclusion Complexation	the unique release characteristics and the protection of unstable and high value specialty flavor chemicals.	limited amount of flavor (9–14%) can be incorporated; very expensive; chance for undesirable adulteration of the flavor due to presence of cyclodextrin

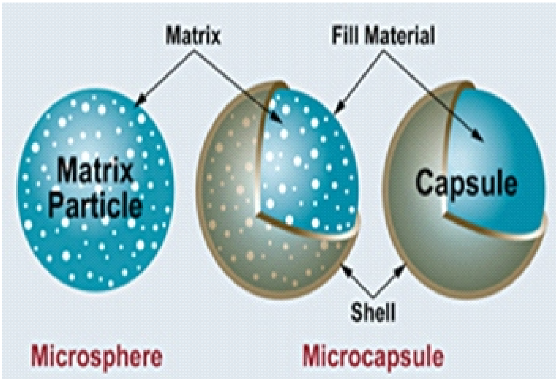
Table-3 : Wall materials used for microencapsulation of fish oil.

Microencapsulation methods	Wall materials used for microencapsulation of fish oil
Spray drying	Gelatin, maltodetrin, casein, lactose, sodium caseinate,dextrose equivalence, highly branched cyclic dextrin, methylcellulose, hydroxypropyl methycellulose, n-octenylsuccinate, derivatized starch/glucose syrup, sugar beet pectin, gum Arabic, corn syrup
Freeze drying	Sodium caseinate, carbohydrate, egg white, gum Arabic, lactose and maltodetrin
Electrostatic layer by layer (multilayer) deposition and spray drying	Lecithin and chitosan
Double emulsification and subsequent enzymatic gelation (fish oil)	Soy protein, whey protein, sodium caseinate, Transglutaminase
Ultrasonic atomization and freeze drying (fish oil)	Chitosan
Electrospraying	Zein prolamine (corn protein)
Spray granulation and fluid bed film coating	Soybean soluble polysachharide (P), maltodextrin, hydroypropyl betacyclodetrin (HPBCD)

produced by this method are matrix type. (Atmane et al., 2006; Zuidam & Shimoni, 2010).

Coacervation : In this method, the core material is emulsified in the protein solution, and formation of coacervate wall is initiated by changing either the temperature, pH, or by adding a concentrated salt solution. The resultant microcapsules are isolated by centrifugation or filtration and might be dried by spray drying or fluid bed drying. The particle size varies from 10 to 800 µm. (Fang & Bhandari, 2010; Zuidam & Shimoni, 2010).

Spray Chilling or Spray Cooling : In the spray chilling, the coating material is melted and atomized through a pneumatic nozzle into a vessel generally containing a carbon dioxide ice bath (temperature -50°C) as in a hot-melt fluidized bed followed by droplets adhere on



particles and solidify forming a coat film. The particle size varies from 20–200 μm. It is used for encapsulation of aroma compounds to improve heat stability.

Fluid Bed Coating : It is widely used in the food, pharmaceutical and cosmetic industry. The major process involved in fluid bed coating are (1) preparation of coating solution; (2) fluidization of core particles; (3) coating material is sprayed through a nozzle on to the particles and film formation is initiated; and (4) drying. The size of the particle varies from 5 to 5000 μm.

Liposome Entrapment : Liposome consists of an aqueous phase that is completely surrounded by a phospholipid-based membrane. When phospholipids, such as lecithin, are dispersed in an aqueous phase, the liposomes form spontaneously. One can either have aqueous or lipid soluble material enclosed in the liposome. Microfluidization, ultrasonication, and reverse-phase evaporation technique can be used to produce different varieties of liposomes for specific purposes. The particle size varies from 10 to 1000 μm. (Anu Puri et al., 2009;mPegg & Shahidi, 2007; Zuidam & Shimoni, 2010).

Inclusion Complexation : In this method, -cyclodextrin is typically used as the encapsulating medium. -cyclodextrin molecule forms inclusion complexes with compounds that can fit dimensionally into its central cavity. These complexes are formed in a reaction that takes place only in the presence of water. This reaction can be accomplished by stirring or shaking the cyclodextrin and core material to form a complex, which could then be easily filtered and dried. Molecules that are less polar than water (i.e., most flavor substances) and have suitable molecular dimensions to fit inside the cyclodextrin interior can be incorporated into the molecule. The particle size varies from 5 to 15 μm. (Pegg & Shahidi, 2007; Zuidam & Shimoni, 2010; Desai & Park, 2005).

Electro spraying : In this method encapsulates are produced in nano size with improved oxidative stability (Sergio et al.2010).

Spray granulation and fluid bed film coating : In this method fish oil is emulsified and spray dried. Then it will be coated with hydroxyl propyl betacyclodextrin. This method is under developmental stage and it need further development for commercial production.

Ultrasonic atomizer : In this method ultrasonic atomizer are used to produce encapsulates relatively narrow size distribution.

Wall material/Coating Material used for microencapsulation of fish oil : The coating material should be capable of forming a film that is cohesive with the core material be chemically compatible and nonreactive with the core material and provide the desired coating properties, such as strength, flexibility, impermeability, optical properties, and stability. Coating material should also have the properties such as stabilization of core material, inert toward active ingredients, controlled release under specific conditions, tasteless, non-hygroscopic, no high viscosity, soluble in an aqueous media or solvent, or melting and economical (Hammad et al., 2011). Wall material/ Coating Material used for microencapsulation of fish oil is given in table-3.

Application of Microencapsulated fish oil in Food Industry : Microencapsulation can potentially offer numerous benefits to the materials being encapsulated. Microencapsulated fish oil can be used in a wide assortment of foods. For example, Novomega, omega-3 fatty acids encapsulated product is marketed for use in bakery products. The encapsulation system of the Novomega is specially formulated for long chain n-3 fatty acids, and results in a product that eliminates strong fish oil tastes and odors. Two other fish oil encapsulated powders, Marinol™ omega-3HS, and Marinol DHA HS are marketed in US. Another omega-3 microencapsulated fish oil powder, MEG-3 has been introduced in the Canadian and US markets. These powders have been included in to bakery, milk and beverage markets (Pszczola, 2005). Bakery products are generally used as a source for incorporation of different nutritionally rich ingredients for their diversification (Sudha et al., 2007). Jeyakumari et al. (2016) observed that cookies fortified with fish oil microencapsulates was comparable with neat sample (without fish oil encapsulates). Yep et al. (2002) have shown that bread enriched with microencapsulated tuna oil (MTO) increases DHA and determined the acute and chronic effects of low doses of long chain (LC) n-3 PUFA (100 mg/day) on plasma LC n-3 PUFA levels using a novel delivery form. Agnikumar et al. (2015) reported that cake fortified with microencapsulated fish oil improved the oxidative stability of the product.

Jeyakumari *et al.* (2016) studied fish oil microencapsulates fortified pasta and noodles. Oxidative studies revealed that fish oil encapsulates incorporated pasta and noodles had lower peroxide value and thiobarbituric acid reactive substances than bulk fish oil added one. Verardo et al. (2009) were studied 1.2% encapsulated fish oil incorporated in Spaghetti and found improved nutritional quality. Shirin et al. (2019) developed microencapsulated fish oil enriched bread and found that there was no significant difference between enriched with 1% fish oil microcapsules and control on texture, appearance and crumb.

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