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Encapsulation of lipophilic bioactive: a Review

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Abstract

The lipophilic food bioactive has attracted great interest by food and pharmaceutical industries due to their potential health benefits. However, the effectiveness of these components is restricted due to poor solubility, oxidation and variable bioavailability. The utilization of these compounds in form of encapsulated one can effectively alleviate these drawbacks. The technologies of encapsulation, including spray drying, coacervation, liposome entrapment, nanoencapsulation, nanogels and nanoemulsion, are discussed in this review paper.

Key words: lipophilic, nanoencapsulation, food.

1. Introduction

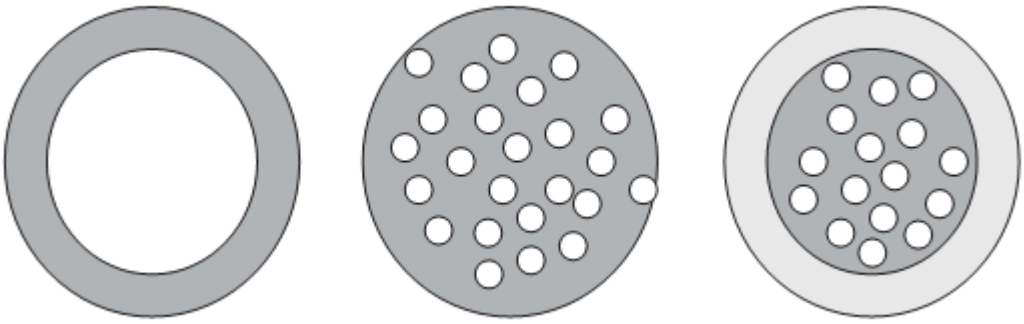
Lipophilic bioactive include food compounds such as vitamins, phytochemicals (e.g. polyphenols and carotenoids), fatty acids (ALA, DHA). These are parts of our nutrition due to its disease prevention and health promoting activities e.g. nutritional value, antioxidant, anti-inflammatory, wound healing, and anti-cancer (Jackson & Paliyath, 2011). However, the use of lipophilic compounds may have been restricted by its use directly in the food system due to poor aqueous solubility, low oral bioavailability and easily oxidation (Ezhilarasi *et al.,* 2013). These high valued functional foods after being subjecting to food processing conditions such as pH, temperature and addition of salts leads to diminish its function values. Therefore it is a need to develop suitable matrix to encapsulate properly using diverse technologies to maintain its profuse health benefits, deliver them to the target site and on time (Fathi *et al.,* 2012).

The advantages of encapsulation of bioactive compounds in colloidal delivery systems are more than with traditional delivery systems: (1) stabilization in aqueous systems (2) protection of bioactive compounds against oxidative degradation (3) controlled release by engineering the dimension and composition of the capsules and (4) enhancement of bioavailability for cell uptake (Sessa *et al.*, 2014).

The objective of this paper is to review the state of the art of various encapsulation methods of food ingredients and wall materials. The review paper also delineates the characterization methods of nanoparticles as well as effect of processing conditions applied in the food industries (temperature, salt and pH) to nano particles.

Encapsulation

Encapsulation may be defined as a process to entrap one substance within another substance, thereby producing particles with diameters of a few micrometer and nanometer range. The substance that is encapsulated may be called the core material and active ingredient. The substance that is encapsulating may be termed as the coating, carrier material and wall material. Two main types of encapsulates might be distinguished (Fig 1), i.e., the reservoir type and the matrix type (Zuidam & Shimoni, 2010).



Reservoir type matrix type coated matrix type

Fig.1 Types of encapsulation

Wall materials

A wide range of wall materials have been used to encapsulate edible oils, including polysaccharides (modified starch, gum Arabic (Tonon *et al.,* 2012), gum Arabic and maltodextrin, (Carneiro *et al.,* 2013) chitosan and maltodextrin (Klaypradit & Huang, 2008), alginate and chitosan (Li & McClements, 2011) and proteins whey (Tonon et al., 2012), soy (Kim *et al.,* 1996), sodium caseinate and caesin (Drusch *et al.,* 2012) sodium caseinate maltodextrins and corn syrup solids (Hogan *et al.,* 2001), gelatin-gum Arabic (Chang *et al.,* 2006).

Encapsulation methods

A wide range of technologies have been developed to encapsulate the active ingredients including spray drying, coacervation, emulsions, liposomes, micellae, nanoparticles, freeze-drying, cocrystallization and yeast encapsulation (Pradhan *et al.,* 2013). Each of these has its own specific strengths and weaknesses in encapsulation, protection, delivery, cost, regulatory status, ease of use, biodegradability and biocompatibility. Among these, emulsions are well known and popular encapsulation and delivery systems for a wide range of lipophilic bioactive molecules, due to their high-efficiency encapsulation, maintenance of chemical stability of encapsulated molecules and controlled release (McClements & Li, 2010).

Liposomes

Liposomes are lipid bilayers encapsulating aqueous space. Owing to the possession of both lipidand aqueous phases, liposomes can be utilized in the entrapment, delivery, and release of water soluble, lipid-soluble, and amphiphilic materials. The underlying mechanism that responsible for the formation of liposomes and nanoliposomes is mainly due to hydrophilic and hydrophobic interaction between phospholipids and water molecules. Dag *et al.,* (2019) conducted a study in which polyphenol-rich green tea extract was successfully encapsulated into liposomes by means of microfluidization.

Nanoencapsulation

Nanoencapsulation involves the formation of active loaded particles with diameters ranging from 1 to 1000 nm (Reis *et al.,* 2006). Compared to micron-sized particles, nanoparticles provide a greater surface area and have the potential to increase solubility due to a combination of large interfacial adsorption of the core compound, enhanced bioavailability, improved controlled release, which enables better precision targeting of the encapsulated materials (Mozafari *et al.,* 2008).

Nanoemulsions

Emulsion technology is generally applied for the encapsulation of bioactives in aqueous solutions, which can either be used directly in the liquid state or can be dried to form powders after emulsification. Basically, an emulsion consists of at least two immiscible liquids, usually as oil and water, with one of the liquids being dispersed as small spherical droplets in the other. Typically, the diameters of the droplets in food systems range from 0.1 to100 mm. Emulsions

can be classified according to the spatial organization of the oil and water phases. A system that consists of oil droplets dispersed in an aqueous phase is called an oil-in-water (O/W) emulsion, whereas a system that consists of water droplets dispersed in an oil phase is called a water-in-oil (W/O) emulsion (McClements *et al.,* 2009). Some of the nanoemulsion based delivery systems are represented in (Table 1).

Table 1: Nanoemulsion based delivery system for food bioactive component

Components	Outcomes	References
Curcumin	Lecithin, Tween20 and sucrose monopalmitate effectively encapsulate curcumin	Artiga-Artigas *et al.,* (2018)
ß-carotene	Medium chain triacylglycerol (MCT), High pressure homogenization: particle size: 142 - 250 nm	Liang *et al.,* (2013)
Lycopene	Tween 20, Butylated hydroxytoulene (BHT) Emulsification evaporation/ High pressure homogenization, particle size: 62-135 nm	Kim, *et al.,* (2014)
Quercetin	Tween 80, Span 20 High speed homogenization, particle size: varied with conditions	Karadag *et al.,* (2013)
Resveratrol	Soy lecithin, Tween20, High pressure homogenization, particle size:128-235 nm	Sessa *et al.,* (2014)

Coacervation

Coacervates are liquid-liquid phase separation phenomenon occurring between oppositely charged biopolymers mainly bonded through electrostatic interaction. These are produced from proteins and polysaccharides. The coacervates formation can be affected by factors such as pH, polymer concentration, polymer mixing ratio, ionic strength and thermal treatments. Coacervation of chia seed protein isolate (CPI) and chia seed gum (CSG) as a function of pH and protein/polysaccharide ratio has been reported by Timilsena *et al.,* (2016). In another study conducted by Gulao, *et al.,* (2016) investigated the effect of pH, polysaccharide concentrations and ionic strength on the formation of polypeptide leucine (PL) and gum arabic complex coacervates. On increasing the polysaccharide concentration decreased particle size may due to dissociation of insoluble complexes and formation of soluble complexes.

Nanostructured lipid carriers (NLCs)

NLCs are consisting of both solid lipid and liquid lipid phase. NLCs are considered to be an advanced delivery system and appeared to overcome the problems of SLNs such as limited loading capacity, burst release of bioactive compounds, and long term physical stability of lipid carriers. The advantages of NLCs are including low toxicity, biodegradation, protection, and slow release (Pardeshi *et al.,* 2012). Lutein-loaded NLCs were fabricated with ω-3 fatty acids as a liquid lipid and carnauba wax and glycerol stearate as solid lipid. The particle sizes and entrapment efficiency of lutein-loaded NLCs were below 200 nm and 89%, respectively (Lacatusu *et al.,* 2013).

Nanosuspensions

Nanosuspensions can be defined as carrier-free nanoparticles containing only pure bioactive compound crystals with minimum surfactant and/or polymer for stabilization purpose (Rabinow, 2004). It has significance for high solubility and fast dissolution rate of poor soluble bioactive components, more loading efficiency, and stability in solid state of core components. These characteristics lead to produce with increased oral adsorption, resistance to hydrolysis and oxidation, and bioavailability.

Nanogels

Nanogels are generally defined as nanosized hydrogel particles formed by physically or chemically cross linked hydrophilic or amphiphilic polymer network. It has been elucidated regarding the fact that nanogels producin high loading capacity, high stability, and environmental conditions stability to ionic strength, pH, and temperature (Raemdonck, *et al.*, 2009)

Spray drying

Spray-drying is the most common technology used in food industry due to low cost. Spray-drying has been successfully used in the food industries for the encapsulation purpose. The spray drying conditions of some of the components are presented in Table 2.

Table 2: Spray drying conditions used for encapsulation and encapsulation efficiency

Encapsulant	**Wall material**	**Spray drying condition**			**Encapsulation efficiency (%)**	**References**
		Inlet temp.	**Outlet temp.**	**Feed rate**		
Olive oil	Gum Arabic, Malto dextrin, gelatin, lactose	165±5 °C	80±5 °C	360-540 ml/h	-	Calvo Magro *et al.*, 2010
Peppermint oil	Gum Arabic, Malto dextrin	200 °C	-	-		Badee *et al.*, 2012
Rapseed oil	Maltodextrin	200±2 °C	100±2 °C	-	79-95	Domain & wasak 2008
Fish oil	Methyl cellulose	160±2 °C	65±2 °C	15 g min^{-1}	-	Kolanowski *et al.*, 2005
Fish oil	Barley protein	180 °C	60±5 °C	-	92.9-100.2	Wang *et al.*, 2011
Linseed oil	Gum Arabic, Malto dextrin, Methyl cellulose, whey protein isolate	175±5 °C	75±5 °C	15 ml min^{-1}	>90	Gallardo *et al.*, 2013
Flaxseed oil	Zein	135 °C	55-60 °C	9 ml min^{-1}	93.26	Condor *et al.*, (201

						1)
Pomegranate seed oil	Skim milk powder	187 °C	-	1.75 g min^{-1}	95.6	Goula & Adamopoulos., (2012)
Macadamia oil	Sodium caseinate, maltodextrin	167 °C	-	1.1 kg/h	-	Laohasongkrama *et al.*, (2011)

Characterization

Characterization of nanoemulsion

Particle size- Static light scattering (highly recommended for general use 100 nm to 1000 μm), dynamic light scattering (recommended for emulsions containing 3 nm to 5 μm droplets).

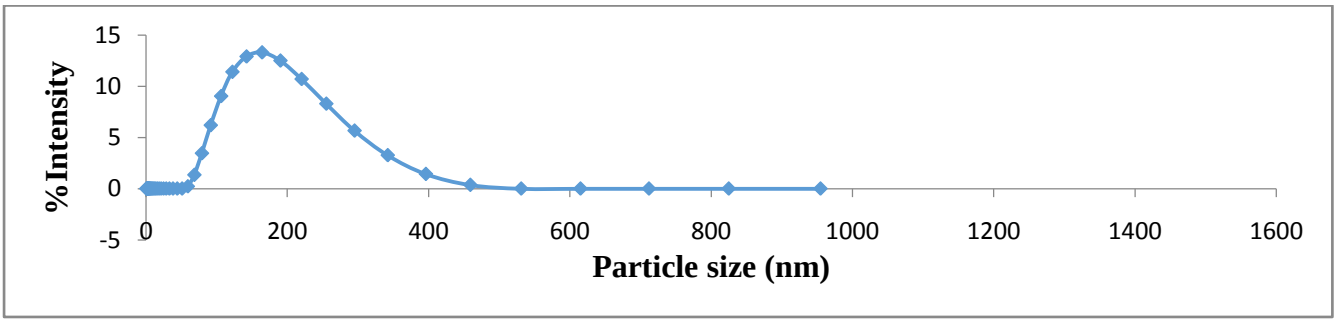


Fig 2: Particle size distributions of omega-3 encapsulated nanoparticles

Zeta potential- The zeta-potential (ζ) is the electrical potential at the "shear plane," which is defined as the distance away from the droplet surface below which the counter-ions remain strongly attached to the droplet when it moves in an electrical field.

Microscopy- A variety of microscopy techniques have been developed to observe these fine features, with the most widely used being optical microscopy, electron microscopy and atomic force microscopy. Various types of chemical stains are available that bind to particular components within an emulsion (e.g., the proteins, polysaccharides or lipids) or that preferentially partition into either the oil phase or the aqueous phase.

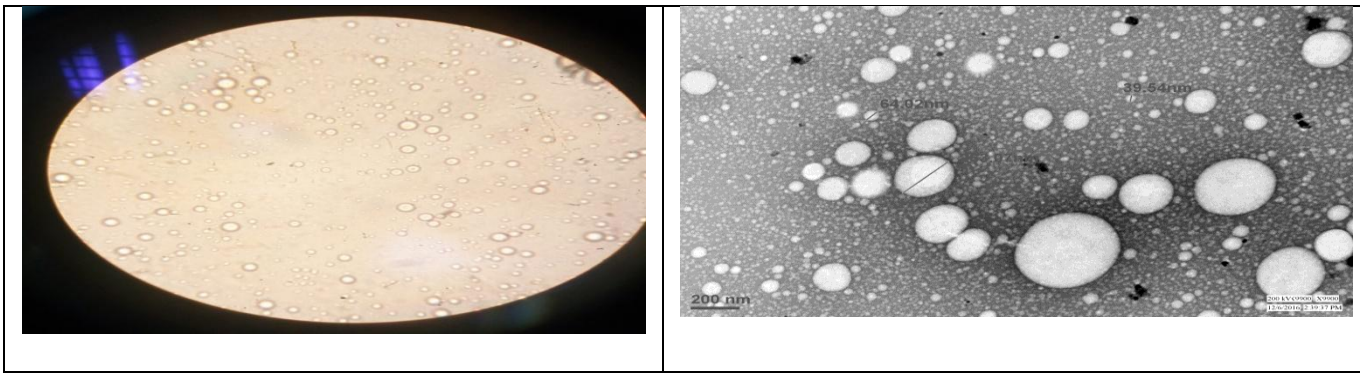


Fig 3: Images of emulsions a) microscopic b) Transmission Electron Microscope

Encapsulation efficiency (%): It is termed as the ratio of bioactive components present in the surface to the total bioactive components (Surassmo *et al.*, 2010).

FTIR- It performs to investigate the functional group, its interaction and stability of all the nanoparticles samples.

Interfacial characteristics - The interfacial characteristics of surfactants plays a major role in determining their ability to fabricate and stabilize emulsions. The interfacial tension decreased as on increase with surfactant level, indicates that the surfactant molecules adsorbed to the oil-water interface and prevent the thermodynamically unfavorable molecular interactions between the oil and water phases. The decrease in interfacial tension on increase with surfactant until a relatively constant value was achieved, indicates that the interfaces had sufficiently saturated (Hunter, 2001).

Environmental stability of nanoparticles

Thermal Processing: Many food emulsions are subjected to some kind of thermal processing during their manufacture or utilization, e.g., sterilization, pasteurization or cooking. It was studied by that polysaccharide-coated oil droplets are often stable to heating because the droplet surfaces biopolymers remain compact and generate electrostatic repulsion at interface. However, the globular protein-coated oil droplets often aggregate when heated above their thermal denaturation temperature, if electrostatic repulsion is very week.

pH and salts: Food products vary considerably in the pH and mineral composition of the aqueous phase, which may have a pronounced impact on their stability. The impact of salt addition on the stability of nanoparticles differs with types of emulsifiers. Polysaccharide-coated oil droplets even at more salt concentration are often stable to aggregation due to strong interfacial steric repulsion. Protein, phospholipid and rhamnolipid coated oil droplets form aggregate on addition of salt reduces the electrostatic repulsion acting between the droplets.

Conclusions

Encapsulation of lipophilic bioactive foods has been approached and developed using many different techniques. Most of the methods have been stated to deliver these bioactive successfully through emulsion matrix. In spite of it, the production of nano foods by food processing industries is still significantly low and needs more consideration from the food regulatory authorities on toxicity and clinical trials point of view prior its use. Therefore still some future scope remained left to understand the interactions between food components for its safe use as well as the physicochemical properties of the nano-carriers.

Conflict of interest:

Authors declare that they have no conflict of interest.

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