Chapter

Microencapsulated Vegetable Oil Powder

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Abstract

Vegetable oil has been increasingly popular among consumption oils as it provides several health benefits such as antioxidant, anti-inflammatory, antivasoconstrictive, antiarrhythmic, antithrombotic, antimicrobial, antihypertension, antiaging, etc. Several applications of vegetable oils in foods, cosmetics, and pharmaceutical industries have been widely researched as it is made from natural products with a safe and reliable process. However, oxidative deterioration and stabilization of vegetable oil provide short shelf life storage with poor consumer acceptance. Thus, this chapter is aimed to give an overview of stabilization of vegetable oils using microencapsulation techniques mostly focusing on emulsion preparation using multilayer emulsion followed by a spray drying technique to obtain vegetable oil powder. Using different wall materials was discussed along with the application for several vegetable oils. Moreover, the characterization of encapsulated vegetable oil powder was summarized for the final product quality and encapsulated process efficiency.

Keywords: microencapsulation, vegetable oil, multilayer emulsion, spray drying, vegetable oil powder

1. Introduction

Vegetable oils are a group of fats that are extracted from seeds or the other part of a seed plant. In 2018/2019, the world production of major oilseeds is forecasted to 604.67 million metric tons (MMT). Three main oilseed productions are soybean (369.32 MMT), rapeseed (71.70 MMT), and sunflower seed (49.83 MMT) [1]. The main oilseed product exporting countries are USA, Brazil, Canada, China, the European Union, and Argentina. USA soybean has been exported to China in the total of 1.3 million tons compared to 10.7 million tons of fruits or vegetables in the last year [1]. It is recognized that vegetable oils and their products have an important role to make the economy of many countries. These oils are an important source of energy and a carrier of fat-soluble vitamins [2]. Common vegetable oils include soybean, rapeseed, sunflower seed, corn, sesame, coconut, rice, etc. Currently, vegetable oil consumption has been increasing compared to animal fat consumption. Three exporters of oilseeds including copra, cottonseed, palm kernel, peanut, rapeseed, soybeans, and sunflower seeds are Brazil (75.28 MMT), the USA (57.20 MMT), and Canada (17.13 MMT) [1].

Vegetable oils are an important renewable resource from nature containing ester mixtures derived from glycerol with chains of fatty acid about 14–20 carbon atoms with different degree of unsaturation [3]. There are composed of mixtures of triacylglycerols (TAG) (>90–95%) with minor diacylglycerols, tocopherols/tocotrienols, and phytosterol ester (<5–10%). Several health benefits of vegetable oils are gastronomic, nutritional, organoleptic, antioxidant, anti-inflammatory, anti-vasoconstrictive, antiarrhythmic, antithrombotic, antimicrobial, antihypertension, antiaging, etc. [4]. The vegetable oils and their components have been growing of interest in food, cosmetics, and pharmaceutical industries as of their natural and safety produce, and the acceptance by the consumer has been found increasingly. Although vegetable oils have gained popularity and interest, they are sensitive to oxidative deterioration and generate several degradation products such as aldehyde, ketones, epoxides, hydroxyl compounds, etc. These changes occurring in vegetable oil affect shelf life, sensory properties, and overall acceptability of products. Microencapsulation technique has been applied as it has the potential to delay lipid oxidation rate of vegetable oils. Several studied have shown that vegetable oil can play an important role in protection against oxidation using microencapsulation technique [5–10]. Microencapsulation (ME) is the technique in which small particle or liquid droplets are coated or are embedded in a homogenous or heterogonous matrix to form small capsules in both dry form and wet form products [11]. However, there are several methods of encapsulated vegetable oil powder include emulsification, spray drying, freeze drying, fluidized bed coating, extrusion, cocrystallization, molecular inclusion, coaxial electrospray system, and coacervation [4, 12]. Therefore, the objective of this chapter is conveying an overview of the microencapsulated vegetable oil powder method and technique. This chapter summarizes the preparation of vegetable oil-in-water emulsion stabilized by proteins and other wall materials, providing information on microencapsulated powder using spray drying, and characterization of microencapsulated powder and application is finally discussed.

2. Microencapsulation

Microencapsulation (ME) is a technique in which solid, or liquid, gaseous active is coated by a coating material to give small capsules aiming to obtain some physical or chemical properties, which can be applied in a food system. The terminology used to describe "microparticle" refers to a particle with diameter from 1 to 1000 μm, irrespective of the interior or exteriors structure. Generally, nanocapsule refers to a particle range from 10 to 1000 nm [13]. Microspheres refer to spherical microparticles, and subcategory of microcapsules applies to microparticles, which have a core surrounded by materials. "Microcapsule" is defined as a spherical particle size that ranges 50–2 mm including a core material where microspheres are spherically empty particles. However, both microcapsules and microspheres are often used synonymously [13]. In addition, some related terms are used alternatively called "microbeads" and "beads." Moreover, some particles greater than 1000 μm can be termed microgranules or macrocapsules.

Encapsulated material located inside small capsules is known as core materials or internal phase or active ingredient, whereas the outer or protective materials are called as wall material, carrier, shell, or encapsulation matrix (**Figure 1**). The wall protects the core materials from environment such as light, oxygen, moisture, etc. Wall materials can be commonly used as both synthetic polymers and biomaterials (carbohydrates and proteins or combination materials). Therefore, the purposes of encapsulation technique are (1) protection of core material from environmental conditions such as oxygen, temperature, moisture, RH, light; (2) masking of odor, taste, and activity of encapsulated materials; (3) controlled release of active compounds (sustained or delayed release); (4) separation of incompatible components;

(5) conversion of liquids to free-flowing solids; (6) increasing the oxidation stability and targeted release of encapsulated materials [14].

Microcapsule models can be classified into three basic categories as monocored, polycored, and matrix types (**Figure 2**) [14]. Monocored microcapsule contains a single hollow chamber within a capsule; however, the polycore microcapsule includes a number of different size chambers within the shell. On the hand, the matrix type of microparticle refers to active ingredients integrated within the matrix of the shell material [14]. Different types of microcapsules such as (i) simple microcapsule, (ii) matrix, (iii) irregular microcapsule, (iv) multicore microcapsule, (v) multiwall microcapsule, and (vi) assembly of microcapsule are shown in **Figure 3** [4].

It has been reported that the size and shape of microcapsules depend on wall materials and the methods used during preparation. The selection of wall materials relies on the properties of core materials, final products, and characteristics such as food-grade product, production cost, low viscosity property at high solid content, emulsifying properties and emulsion stability, ability of holding core materials in their structure without any reactivity during processing or storage, control release of core material, and protecting core materials from environmental conditions [15, 16]. The common wall materials of microencapsulated oil can be classified into three groups including carbohydrate, protein, and lipids and wax as summarized in **Table 1** [16].

An emulsion technique has been widely used for the preparation of encapsulation. Oil-in-water emulsions (O/W) are commonly used in cosmetics, pharmaceutical, and food industries for encapsulation by using different core materials.

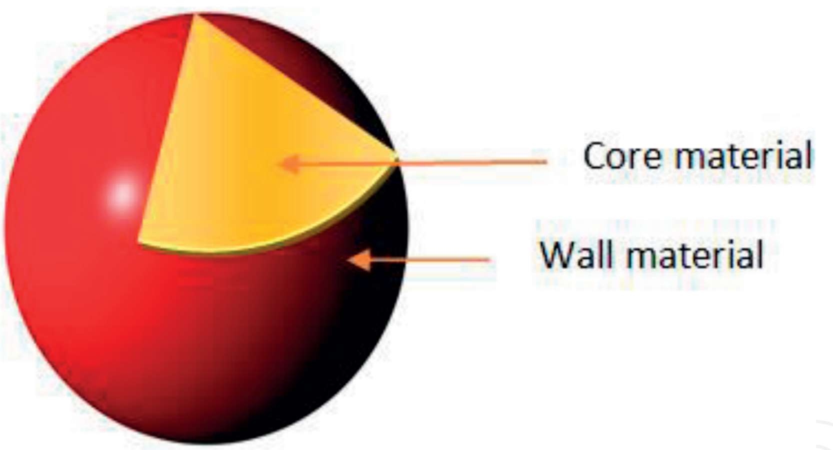

Figure 1.
Schematic diagram of microencapsulated material structure (adapted from [4]. Copyright 2015 by © Institute of Food Technologists).

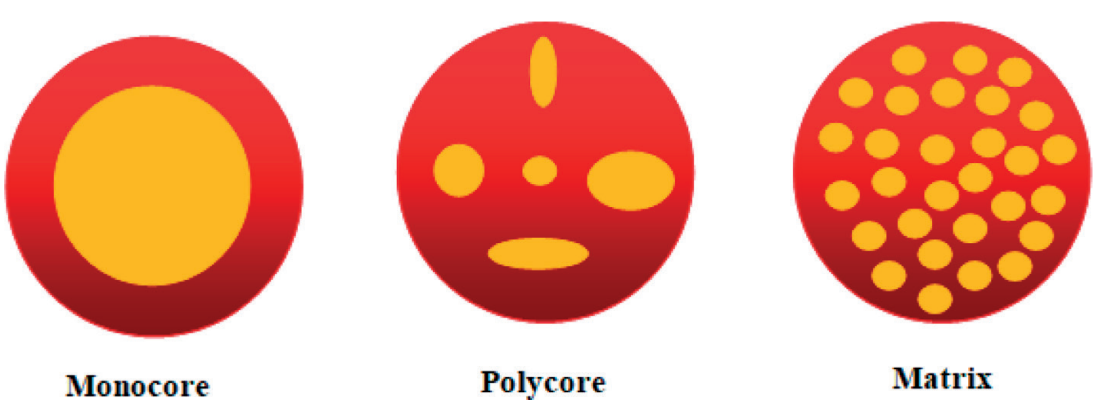

Figure 2.
Schematic diagram of microcapsules model (adapted from [14]. Copyright 2009 by DESIDOC.

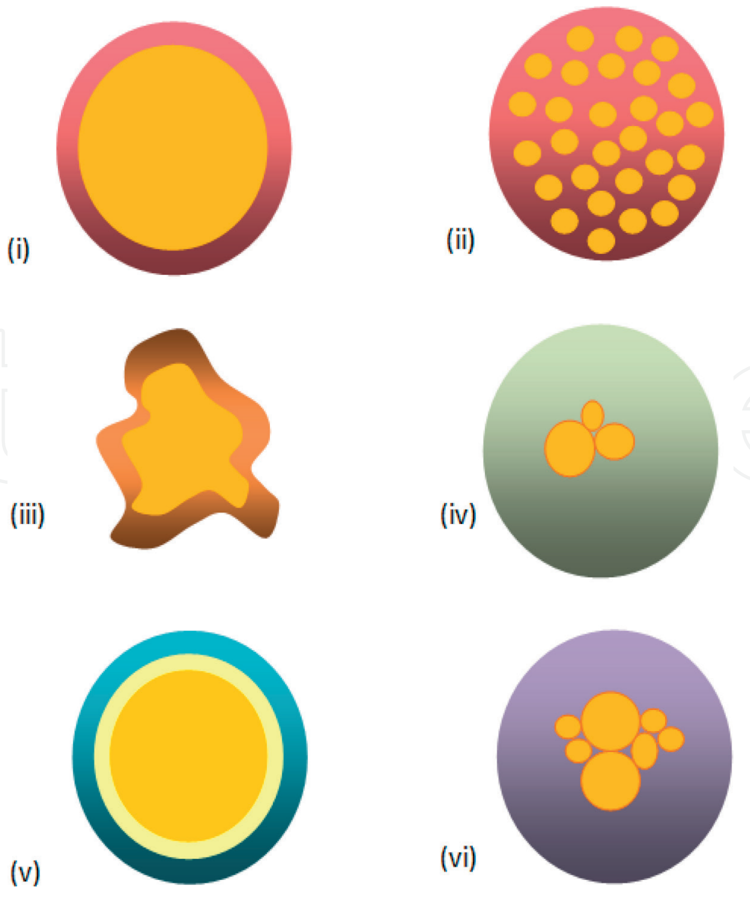

Figure 3.
Different types of microcapsules: (i) simple microcapsule, (ii) matrix, (iii) irregular microcapsule, (iv) multicore microcapsule, (v) multiwall microcapsule, and (vi) assembly of microcapsule (adapted from [4]. Copyright 2015 by © Institute of Food Technologists).

Traditionally, O/W emulsions are prepared by oil homogenization with an aqueous phase containing one or more emulsifiers. However, the achievement of emulsion forming is limited depending on emulsifier properties such as on ionic strength, pH, and temperature, affecting emulsion stability and encapsulated compound [17, 18]. Guzey and McClements [17] indicated that one strategy to improve protection against environmental stresses is to create covalent protein-polysaccharide complexes and another strategy is to create multiple layers of emulsifiers and/or polyelectrolytes using a layer-by-layer (LBL) electrostatic deposition technique. According to LBL technique, it is based on LBL deposition of polyelectrolytes onto oppositely charged surfaces due to electrostatic attraction. Firstly, a primary emulsion containing an ionic emulsifier has produced a small oil droplet during homogenization. Thereafter, a secondary emulsion containing droplets coated with a two-layer interface is created using opposite charge polyelectrolytes with the primary emulsion. Finally, the secondary emulsion is mixed with another oppositely charge polyelectrolytes to create a tertiary emulsion. The procedure can be repeated to form oil droplet coated by interfaces containing more layer (**Figure 4**). The multilayer emulsions were reported having better stability to environmental stress than O/W emulsion with single-layer interfaces [3, 17, 19].

It has been found that LBL technique provides a multilayer emulsion with satisfying properties. However, the stable multilayer emulsions using an LBL technique depend on biopolymer properties, for example, charge density, molecular weight, conformation, emulsifier layer thickness, and bulk physicochemical condition. In addition, there have been several techniques applied for microencapsulation of vegetable oil powder. Drying process is the method commonly used for microencapsulation of vegetable oil, which changes liquid into powder. Spray drying is the most widely used

Carbohydrate	Proteins	Lipids and wax
Plant-based carbohydrate:	Plant-based protein:	• Milk fat
• Maltodextrin	• Soy protein	• Phospholipid
• Starch	• Pea protein	• Beeswax
• Cellulose	• Barley protein	• Carnauba wax
• Gum arabic	• Zein	
• Guar gum	• Gluten	
• Pectin	Animal-based protein:	
• Galactomannans	• Casein	
• Cyclodextrin	• Whey protein	
• Mesquite gum etc.	• Gelatin	
Marine-based carbohydrate:		
• Carrageenan		
• Alginate		
Microbial- or animal-based carbohydrate:		
• Xanthan		
• Chitosan		
• Dextran		
• Gellan		

Source: [16].

Table 1.
Different wall materials used for microencapsulation.

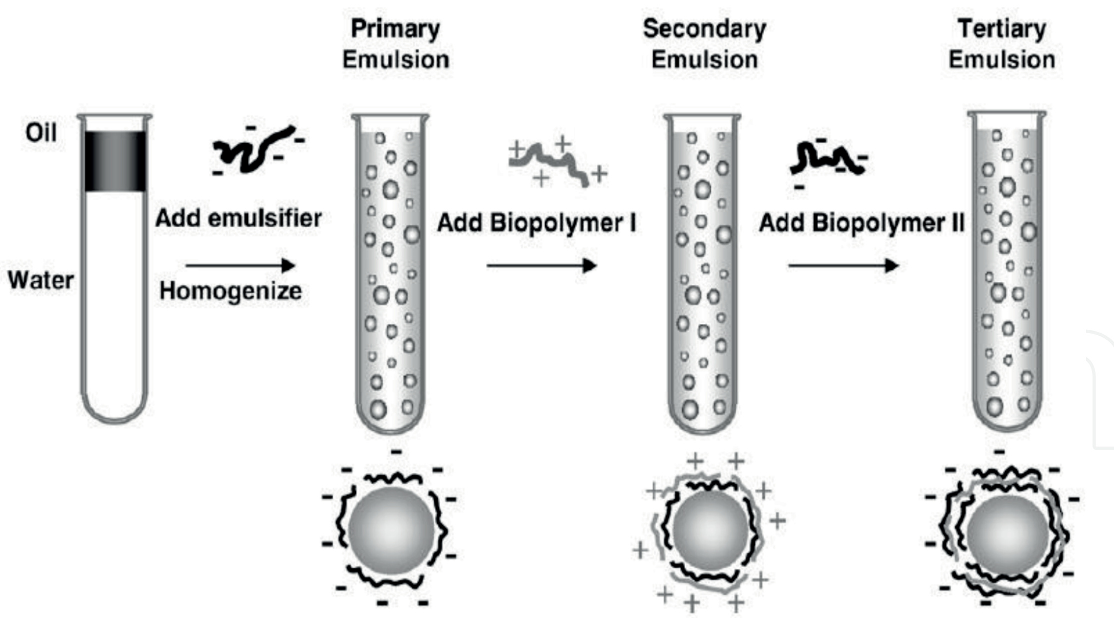

Figure 4.
Schematic representation of layer-by-layer technique producing multilayer emulsions (reproduced with permission from [17].

encapsulation technique in the food industry that is a relatively simple, continuous, and low-cost commercial process [4]. The microencapsulation using spray drying involves atomization and drying of solution, emulsion, suspension, slurry, and paste to produce solid material. It contains (1) preparation of emulsion sample, (2) atomization of the emulsion into fine droplets, (3) droplet-hot-air contact, (4) evaporation of droplet water, and (5) recovery of powder (**Figure 5**) [20]. Generally, the spray drying

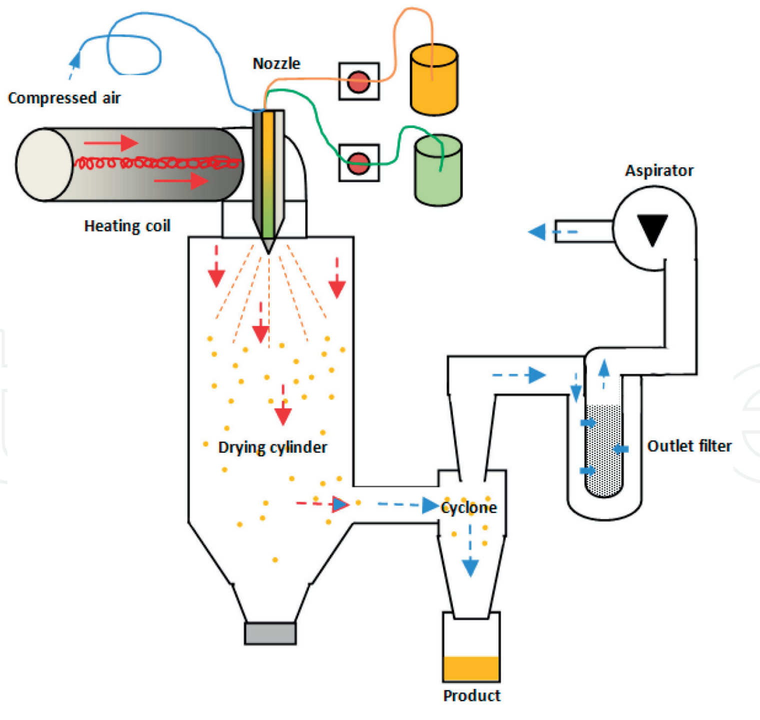

Figure 5.
Schematic representation of spray dryer.

has been used to produce the encapsulation of vegetable oil in the food industry [8, 9, 21–24]. The spray drying process conditions (inlet and outlet temperature, nozzle size, feed rate, etc.) have been found to affect the characteristics and properties of encapsulations. However, the optimum drying condition should obtain minimized fat-free surface powder. It was reported that low inlet and outlet temperatures can reduce the viscosity and the diffusivity of fat. Moreover, large emulsion droplet and nozzle size provide a large powder with low surface area and low fat-free surface [25–28]. The advantages of spray drying compose of simple process, fast and easy to scale up, availability of machinery, low production cost, varied particle sizes, and excellent dispersibility in media. However, some limitations of spray drying were stated such as loss of core material during processing and oxidation of flavoring compounds [29, 30]. In addition, not only spray drying technique was selected to apply for encapsulation process, but different drying techniques are also available for vegetable oil encapsulation such as freeze drying, fluidized bed spray drying, nozzleless electrostatic atomization spray drying, and supercritical carbon dioxide spray drying [25, 26, 31, 32].

3. Vegetable oil-in-water emulsion preparation using microencapsulation technique

Vegetable oils such as soybean, sesame, sunflower, flaxseed, coconut, rice, etc. have been found as major sources of edible oil, which takes place for almost 70% of edible oil. They are composed primarily of triglycerides, esters of one molecule of glycerol, and three molecules of fatty acids. Triglycerides are the most abundant component found in lipid (more than 90%). On the other hand, a vague variation of free fatty acid was reported (0.3–9.5%) depending on a plant source [33]. Different fatty acids were classified by the nature of the hydrocarbon chain. This chain length can vary from 4 to 24 carbon atoms and can be classified as saturated (without a double bond, SFA), monounsaturated (one double bond, MUFA), or polyunsaturated (two or more double bonds, PUFA), which contains 18 carbons with different saturation degree. The position of fatty acids on the glycerol molecule can be in the 1, 3, or 2 positions depending on saturation. Glycerides with saturated fatty acid in this position usually have a high melting point and poor solubility, which can cause nutritional problems and poor digestibility [33].

Generally, fatty acid composition of vegetable oils is formed by a mixture of saturated (SFAs) and unsaturated (UNFAs) fatty acids classified by a number of unsaturated bonds as monounsaturated (MUFAs) or polyunsaturated fatty acids (PUFAs). Nevertheless, each of the analyzed vegetable oils has specific fatty acid distribution depending on their plant sources. Thus, their impact on human health could be assessed according to individual fatty acids because of their different influences on human health and risks of serious diseases [31]. Recently, nutritionists have recommended vegetable oils as an important part of a healthy diet due to their high contents of fatty acids (FAs) [31].

3.1 Soybean oil

Soybean oil is the important seed oil produced in the world due to its high quality and low-cost production. Soybean oil has 15% of saturated fatty acid and 80.7% of unsaturated fatty acid (50.8% linoleic acid content and 6.8% linolenic acid). Soybean oil contains a saturated, monounsaturated, and polyunsaturated fats in healthy proportions (SFA:MUFA:PUFA = 16:24:58). Linoleic acid (omega-6) is the major polyunsaturated fatty acid found in oil; phytosterols, especially Β-sitosterol, inhibit cholesterol absorption and reduce blood LDL cholesterol levels by 10–15%. Moreover, it contains several bioactive compounds such as antioxidant vitamin E, a powerful lipid soluble vitamin, which is important to maintain the integrity of cell membranes and protect them from harmful reactive oxygen-free radicals; vitamin K, an essential element in promoting bone formation and strengthening, and neuronal protection in the brain [32]. Soybean oil provides several advantages and disadvantages compared to other vegetable oils. The advantages of soybean oil include (1) a high content of unsaturated fatty acid, (2) wide temperature range of liquid state, (3) hydrogenated selectively for blending with semisolid and liquid oil, (4) source of nutrients (such as flavonoids and isoflavonoids, phenolic acids, phytoalexins, phytosterols, proteins, and peptides) and mineral (such as copper, manganese, molybdenum, phosphorus, potassium, B vitamin, and omega-3 fatty acids (alpha-linolenic acid) [32, 33]. The disadvantages of soybean oil display a large number of phosphatides, which have to be removed by processing technique and high levels of linolenic acid, which is responsible for its flavor and odor reversion [33]. Several encapsulation techniques for soybean oil have been studied [3, 34]. Spray-dried soybean oil emulsions were made of whey protein, lactose, and soybean oil. It is reported that the ability of whey protein used for soybean oil encapsulation is moderate and the soybean was found in low quality when compared to sodium caseinate under dry and humid atmosphere storage condition (RH 75% for 4 days). Moreover, the fat releasing was observed on powder surface due to some critical amount of lactose containing in powder comparing the powder containing a small amount of lactose [21]. Moreover, the application of electrostatic atomization for soybean oil encapsulation has been reported [25]. W/O emulsion containing glycine and taurine as the wall materials was prepared. The result was shown that the oxidative stability of soybean oil during high-temperature storage was improved.

3.2 Sesame oil

Sesame oil contains 80% unsaturated fatty acids. Oleic and linoleic acids are the main fatty acids. It contains less than 20% of a saturated fatty acid including palmitic acid and stearic acid. The fatty acid composition is 40.7–49.3% of linoleic, 29.3–41.4% oleic, 8.0–10.3% palmitic, and 2.1–4.8% stearic acids in the seed oil [35]. Moreover, sesame oil is also rich in γ-tocopherols (90.5%) [36]. The crude sesame oil contains lignans such as sesamin (293–885 mg/100 g oil), sesamolin (123–459 mg/100 g oil), and sesamol (trace–5.6 mg/100 g oil) [33]. The sesame lignans have been reported to inhibit lipid oxidation and to enhance antioxidant activity of vitamin E in lipid peroxidation systems [37]. All these lignans have multiple physiological functions including inhibiting cholesterol absorption from the intestine, reducing 3-hydroxy-3-methyl-glutaryl CoA reductase activity in the liver microsomes [38], and inhibiting hepatic endoplasmic reticulum stress and apoptosis in high-fat-diet-fed mice [39]. Onsaard et al. [40] applied a multi-layer emulsion for sesame oil aiming to investigate the influence of maltodextrin and environmental stresses (pH, NaCl, and sucrose) on the stability of sesame oil-in-water emulsions containing droplets stabilized by WPC-k-carrageenan membranes. The primary emulsion containing whey protein concentrate-coated droplets was prepared by homogenization. The secondary emulsion containing whey protein concentrate-k-carrageenan was produced by mixing of the primary emulsion with an aqueous k-carrageenan in the absence or presence of maltodextrin solution. There were no significant changes in mean droplet diameter and z-potential of droplets at any maltodextrin concentration (0–30%) or a dextrose equivalent (10 and 15) after 24 h storage. The apparent viscosity of emulsions was increased when the maltodextrin concentration increased. The secondary emulsion containing 15% maltodextrin with dextrose equivalent of 10 provided the stability to aggregate at pH 6–8, NaCl 300 mM, and sucrose 0–20% [40]. Onsaard et al. [8] also studied the oxidation stability of encapsulated sesame oil powder by spray drying. Microencapsulated sesame oil powder was prepared from sesame oil-in-water emulsions containing 15% sesame oil, 0.5% whey protein concentrate, 0.2% κ-carrageenan, and 0–30% maltodextrin with a dextrose equivalent (DE) of 10 using spray drying method. They found that the microencapsulated powder provided high encapsulation yields (86.73%) and low moisture content (3.19%) and water activity (aw = 0.28). The powder exhibited a spherical shape with a few cracks on the surface. They reported that no significant difference in TBARS value was observed during storage at ambient temperature, cold storage temperature, and frozen temperature for 30 days storage ($p > 0.05$). They also suggested that using κ-carrageenan as a secondary layer can improve oxidation stability. They suggested that to the emulsion containing anionic droplets stabilized by interfacial membranes, comprising whey protein concentrate/k-carrageenan/maltodextrin can be used to produce microencapsulation of sesame oil using spray drying technique. Therefore, the powder performed better in protecting the sesame oil against oxidation during storage [8].

3.3 Sunflower oil

Sunflower oil contains a high content of polyunsaturated fatty acids (PUFA) mainly linoleic acid (18:2 n-6) including 68–72% of total fatty acid content. Moreover, it is considered to display an excellent hypocholesterolemic action, which can reduce cardiovascular risk [41]. The other important component of sunflower oil is vitamin E (α-tocopherol). Its high level of vitamin E is helpful for antioxidant activity [42]. Sunflower oil has been encapsulated in starch matrices (native potato starch, water, glycerol, and emulsifier) by extrusion. Extrusion processing parameters such as screw speed, the presence of die head, throughput, melt temperature, and especially the screw configuration play an important role in the development of the dispersed phase morphology [43]. Domian et al. [44] studied sunflower oil microencapsulated using a spray drying method in the matrix of trehalose and whey protein isolate or sodium caseinate. The microencapsulated powder was able to prevent oil oxidation after observing agglomeration during 3 months storage [44]. Belingheri et al. [45] reported that high-oleic sunflower oil carried on porous starch as an alternative to spray drying does not undergo significantly higher oxidation than traditionally spray-dried sunflower oil. They have suggested that plating on porous starch could be a suitable technological alternative to spray drying for flavor encapsulation [45].

3.4 Flaxseed oil

Flaxseed oil is a great source of ω-3 fatty acids. It contains 73% polyunsaturated fatty acids (PUFA), 9% saturated fatty acids, and 18% monosaturated fatty acids [46]. Major fatty acids in flaxseed oil are α-linolenic acid (c18:3; ω-3) (39.90–60.42%), linoleic acid (c18:2; ω-6) (12.25–17.44%), oleic acid (c18:1) (13.44–19.39%), stearic acid (c18:0) (2.24–4.59%), and palmitic acid (c16:0) (4.90–8.00%) [47]. α-Linolenic acid is an essential fatty acid as a precursor of the important long-chain polyunsaturated fatty acid eicosapentaenoic (EPA) and docosahexaenoic acid (DHA) [48]. Goyal et al. (2014) reported that flaxseed oil, fibers, and flax lignans benefit to the reduction of cardiovascular disease, atherosclerosis, diabetes, cancer, arthritis, osteoporosis, autoimmune, and neurological disorders [49]. Although the flaxseed oil is high in antioxidant activity, it can be oxidized after extraction and purification. Microencapsulation technology was suggested to protect PUFAs oil against oxidation, improving their manipulation, modulating their release, and masking their unpleasant test and odor. Increasing the stability of flaxseed oil by microencapsulation process is based on ionic gelation through vibrating nozzle extrusion technology, using pectin as wall material [48]. The authors applied two different drying methods, passive air drying, and fluidized bed drying. The results show that the fluidized bed drying method provided the 20-fold faster and higher payload. Under accelerated storage, higher stability of the encapsulated flaxseed oil powder was found compared to bulk oil [48]. Rubilar et al. [50] optimized the process condition to improve the microencapsulation efficiency of flaxseed oil using a spray drying technique. The results showed that higher microencapsulation efficiency values were obtained with a high concentration of encapsulating wall (30% wall material concentration, 14% oil concentration, and maltodextrin/gum arabic wall type). The microencapsulation of flaxseed oil can enhance the oxidation stability, which can be applied for soup powder enriched with microencapsulated flaxseed oil as a source of ω-3 [50]. Spray-dried flaxseed oil emulsions were prepared by chickpea or lentil protein isolate and maltodextrin. The oxidation stability of encapsulated flaxseed oil was found over a storage period of 25 days at room temperature, and 84.2% of the encapsulated flaxseed oil within the gastrointestinal environments was delivered [51].

3.5 Coconut oil

Coconut oil is edible oil extracting from a kernel of mature coconut palm (*Cocos nucifera*). The coconut oil is the white or slightly yellowish color at a temperature above 26°C and its strong odor or flavor is due to δ- and γ-lactones [2]. The oil contains triacylglycerols (84.0–93.1%), 1,2-diacylglycerols (1.5–5.1%), 1,3-diacylglycerols (1.2–2.1%), monoglyceride (1.0–7.0%), free fatty acids (1.0–2.6%), phospholipids (0.03–0.4%), and glycolipids (0.2–0.35%) [52]. Hui et al. [33] have reported that coconut oil contains 90% saturated fatty acids and 10% unsaturated fatty acids. Medium chain triglycerides (MCTs) are the main components of a fatty acid containing lauric acid (40–50%), myristic acid (13–19%), and

Encapsulating ingredient	Wall material	Encapsulation process	Encapsulation Efficiency (EE) Encapsulation yield (EY)	Oil content	Particle size	References
Soybean oil	Whey protein/lactose	Spray drying	—	30%	0.4 µm	[25]
	Taurine and glycine	Nozzleless electrostatic atomization	—	2.35% and 8.56%	~0–15 µm	
Sesame oil	Whey protein concentrate, κ-carrageenan, and maltodextrin	Spray drying	EY 86.73%	15%	570–650 nm	[8, 40]
Sunflower oil	Native potato starch/glycerol/emulsifier	Extrusion	—	4 µl	15.3–53.4 µm	[43]
	Trehalose/whey protein isolate or sodium caseinate (NaCas)	Spray drying	EE 96–99%	22%	10–70 µm	[44]
	Maltodextrin / hydroxypropylmethylcellulose	Spray drying	EE 73.13–87.00%	—	—	[9]
	Gum arabic and maltodextrin/porous starch	Spray drying	—	20%	—	[45]
Flaxseed oil	Pectin	Vibrating nozzle extrusion/ fluid bed	EE 98%	15%	862–1463 µm	[48]
	Maltodextrin/gum arabic	Spray drying	EE 54.6–90.7%	14 and 20%	17.6 and 23.1 µm	[50]
	Chickpea protein/lentil protein isolate/ maltodextrin	Spray drying	EE 88 and 86.3%	20%	16.3–24.0 µm 21.0–26.1 µm	[51]
Coconut oil	Gelatin solution and maltodextrin	Spray drying	EE ~82% EY ~90%	14.66%	10.3–6.0 µm	[22]
	Maltodextrin/sodium caseinate/soy lecithin	Supercritical carbon dioxide spray drying	EE 73–80%	11.6%	27–72 µm	[57]
Rice bran oil	Tapioca starch/soya protein isolate	Spray drying	EE 76.97%	20%	—	[62]
	Jackfruit seed starch/whey protein isolate	Spray drying	EE 85.90%	20%	3.40–300.51µm	[63]

Table 2.
Application of encapsulated vegetable oils using different drying techniques.

palmitic acid (4–18%) [33]. Coconut oil, especially virgin coconut oil (VCO), has been claimed as a health benefit product such as antioxidant, anti-inflammatory, lipid-lowering, and cytoprotective efficacies due to its higher polyphenolics [53]. It also has been reported that coconut oil exhibited antioxidant property and prevented the peroxidation of lipids both in vitro and in vivo conditions [54]. Moreover, MCTs have been reported as a human health benefit such as weight and glucose control, as well as lipid metabolism and acting as a tumor inhibitor when consumed in a diet [55, 56]. Application of ultrasound for microencapsulation of coconut milk fat using spray drying has been studied by Le et al. [22]. It was reported that using a mixture of coconut milk, gelatin solution, and maltodextrin as a wall material was found successful [22]. On the other hand, VCO microcapsules from oil-in-water (O/W) emulsion using supercritical carbon dioxide spray drying have been reported by Hee et al. [57]. The authors prepared an O/W emulsion by using maltodextrin, sodium caseinate, and soy lecithin as wall materials before supercritical carbon dioxide spray drying was conducted. This result has found a minor effect on antioxidant activity and fatty acids composition of encapsulated coconut oil [57].

3.6 Rice bran oil

Rice bran oil can be extracted from a hard outer brown layer of rice caryopsis during milling. The compositions of curd rice bran oil are 90–96% saponifiable lipids, 83–96% triacylglycerols (TAG), 3–4% diglyceride, 6–7% monoglyceride, 2–4% free fatty acids, 3–4% waxes, 6–7% glycolipids, 4–5% phospholipids, and 4.2% unsaponifiable lipids. The fatty acid compositions of rice bran oil are 0.3% myristic acid (C14:0), 15.0% palmitic acid (C16:0), 1.7% stearic acid (C18:0), 43.0% oleic acid (C18:1), 37.4% linoleic acid (C18:2; ω-6), and 1.5% linolenic acid (C18:3; ω-3) [33]. Rice bran oil contains vitamin E (α-tocopherol, β-tocopherol, α-tocotrienol, and β-tocotrienol), γ-oryzanol, and phytosterols, which are known as antioxidants [58, 59]. In addition, rice bran oil provides several health benefits such as reducing cholesterol, cardiovascular health benefits, and antitumor activity [60, 61]. Microencapsulation of rice bran oil has been reported using a spray drying technique at 140°C inlet air temperature and a combination of different wall materials (tapioca starch and soy protein isolate). This encapsulated rice bran oil powder provided a high encapsulation efficiency and high γ-oryzanol content with low peroxide value [62]. Moreover, Murali et al. [63] optimized rice bran oil encapsulation condition using jackfruit seed starch and whey protein isolate blend as wall materials by spray drying technique. They found that rice bran oil emulsion made with 20% rice bran oil, 3:1 of jackfruit seed starch and whey protein isolate ratio, and 140°C spray drying inlet temperature provided a high encapsulation efficiency and low peroxide value microcapsules [63].

According to several researches reported and reviewed in this chapter, the application of encapsulated vegetable oil offers several benefits to the food industry are summarized in **Table 2**.

4. Characterization of microencapsulated vegetable oil

There are several encapsulated vegetable oil powder characteristics used for characterization of encapsulated powder aiming to ensure that encapsulation techniques can be applied to stabilize the vegetable oil powder in physical, chemical, and physicochemical properties as concluded in **Table 3**.

Encapsulated characterizations	Indicators	Measurements	References
Particle characterizations	Particle size	Dynamic light scattering technique	[8, 44, 57, 66]
	Distribution and mean particle size	Laser light diffraction	[8, 44, 57]
	Zeta potential (ζ-potential)	Surface charge	[8]
	Particle morphology	Scanning electron microscopy (SEM) or transmission electron microscopy (TEM)	[8, 21, 23, 25, 48, 57, 65]
	Moisture content	Hot air oven moisture analyzer	[23, 57, 66]
	Bulk density	Volumeter	[44]
Oxidative stability (under accelerated storage conditions)	Peroxide value	Peroxide	[8, 44, 48]
	2-Thiobarbituric acid reactive substances (TBARS)	Malondialdehyde	[8]
	p-Anisidine value (p-AV)	p-Anisidine	[48]
Thermal analysis	Melting point Thermal profile	Differential scanning calorimeter (DSC) Thermal gravimetric analysis Dynamic mechanical analysis	[67]
Amount or payload	Oil content	High-performance liquid chromatography (HPLC), gas chromatography (GC), or gas chromatography/mass spectrometry (GC/MS)	[25, 48, 57, 66]
	Interaction between materials in encapsulated emulsions	Fourier transform infrared (FT-IR) technique	[23]
	The difference between total and free oil concentration on encapsulation	Encapsulation efficiency (EE)	[57, 66]

Table 3.
Different characterization of microencapsulated vegetable oils.

4.1 Particles characterization

- Particle size, distribution, and mean particle size can be determined by dynamic light scattering technique that has the advantage of being fast and noninvasive, but it does require low particle concentrations [64].

- Zeta potential (ζ-potential) of particles is a scientific term for electrokinetic potential in particles dispersions and a measure of surface charge of particles that reflects their long-term stability.

- Particle morphology: scanning electron microscopy (SEM), transmission electron microscopy (TEM), and electron spectroscopy can visualize surface morphology, dispersed and agglomerated particles, and surface functionalization [65]; in addition, transmission electron microscopy (TEM) or dynamic light scattering.

- Moisture content and bulk density of encapsulated powders.

4.2 Oxidative stability of encapsulated particles

In an approach to evaluating the oxidative stability of oil, the encapsulated particles are evaluated for oxidation at storage times, for example, peroxide value, 2-thiobarbituric acid reactive substances (TBARS) and headspace analysis used to determine the production of propanal and hexanol as indicators of vegetable oil oxidation.

4.3 Thermal analysis

This is one of the popular analyses where the properties of microencapsulated vegetable oil are studied as they change with temperature. Several methods are used:

- Differential scanning calorimeter (DSC): heat flow changes versus temperature or time
- Thermal gravimetric analysis: mass change versus temperature or time
- Dynamic mechanical analysis: measures storage modulus (stiffness) and loss modulus (damping) versus temperature, time, and frequency

4.4 Content or payload

- High-performance liquid chromatography (HPLC)
- Gas chromatography (GC) or gas chromatography/mass spectrometry (GC/MS)
- Fluorescent
- Fourier transform infrared (FT-IR) technique
- Thermal gravimetric analysis
- Encapsulation efficiency (EE)

5. Conclusion

Vegetable oil can be stabilized by using microencapsulated technique. The successful preparation technique is suggested by using multilayer emulsion followed by spray drying. Mostly, wall materials are prepared from a mixture of polysaccharide and protein in order to coat vegetable oil droplets by means of creating covalent protein-polysaccharide bond with a slight usage of emulsifier. The encapsulated vegetable oil powder expresses low oxidative deterioration with chemical and thermal stabilities, which can be applied in different food systems.

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Conflict of interest

The authors declare no conflict of interest.

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