

Microencapsulation of Olive Oil: A Comprehensive Review

Donia Chaabane¹, Asma Yakdhane¹, Gyula Vatai¹, András Koris^{1*}, Arijit Nath¹

¹ Department of Food Engineering, Institute of Food Science and Technology, Hungarian University of Agriculture and Life Sciences, H-1118 Budapest, 44 Ménesi street, Hungary

* Corresponding author, e-mail: koris.andras@uni-mate.hu

Received: 24 November 2021, Accepted: 08 February 2022, Published online: 18 February 2022

Abstract

Olive oil has been received a great importance around the globe because it provides unique functional value. Olive oil prevents the risks of several chronic and acute metabolic disorders because it is enriched with monounsaturated fatty acids, antioxidant phenolic compounds, vitamin E and vitamin K. Unfortunately, oxidative deterioration of fatty acids in olive oil provides short shelf life and reduces biological activities. It is responsible for undesirable organoleptic properties. It may be believed that one of the solutions to preserve the quality of olive oil is microencapsulation. In this review, comprehensive information about techniques to prepare olive oil microcapsule is represented. To prepare olive oil microcapsule, emulsification of olive oil with different wall materials (matrixes) has been adopted as a primary step. Subsequently, dehydration of emulsion by spray drying or freeze drying or coacervation process has been adopted to prepare olive oil microcapsule. Moreover, microcapsule of olive oil has been prepared by extrusion technology. Biopolymers, such as proteins and polysaccharides have been used as wall material for encapsulation of olive oil. As stable emulsification is one of the important issues to produce microcapsule, several emulsifiers, such as lecithin, tween 20 have been used during emulsion preparation. Different characteristics of the microcapsule of olive oil are summarized because it is influenced by several factors during preparation of microcapsule. In later exercise, several applications of encapsulated olive oil in food, pharmaceutical and cosmetic industries are represented in a comprehensive way. It may be expected that this review article will receive attention in industries and academic sectors.

Keywords

microencapsulation of olive oil, emulsification, drying, characterization of microcapsule, application of olive oil microcapsule

1 Introduction

Olive oil is obtained from the fruit of the olive tree (*Olea europaea* L.). It is widely produced in Spain, Italy, Tunisia, Greece and Turkey. For a long time, in the diet of mentioned countries, three main grades of olive oil, such as refined, virgin and extra virgin olive oil were received a great importance [1]. Olive oil is highly appreciated for its fine taste and aroma as well as for its nutritional properties [2]. Presently, olive oil is used to prepare ketogenic diet. Due to its unique biological importance, application of olive oil is not limited within diet chart and to prepare cuisines. Its application to develop biopharmaceuticals and cosmetics is noteworthy [3]. Olive oil offers antioxidant, anti-inflammatory and antibacterial activities. It reduces the risk of several chronic and acute metabolic disorders, including cardiovascular diseases, Alzheimer's disease, cancer, type 2 diabetes, obesity and rheumatoid arthritis [4]. Therefore, acceptance of olive oil is not limited within Mediterranean region. In present

era, it crosses the boundary of mentioned countries and received popularity around the globe [5].

Olive oil is enriched with monounsaturated fatty acids (ω -6 and ω -3 fatty acids), phenolic antioxidant compounds, vitamin E and vitamin K. Composition of olive oil may differ by several reasons, such as zone of cultivation, latitude, climate, quality of soil, genetic variety and maturity of olive fruits [6].

Dietary fat plays a major role in human nutrition and diet. Nutritional benefits of olive oil are primarily related to the fatty acid composition. Virgin olive oil contains two main fractions, such as saponifiable fraction (98.5–99.5%) and unsaponifiable fraction (0.5–1.5%). Saponifiable fraction consists of monoglycerides, diglycerides, triglycerides, free fatty acids and phospholipids. Unsaponifiable fraction of olive oil is enriched with essential ingredients of sterols, hydrocarbons, tocopherols, coloring pigments,

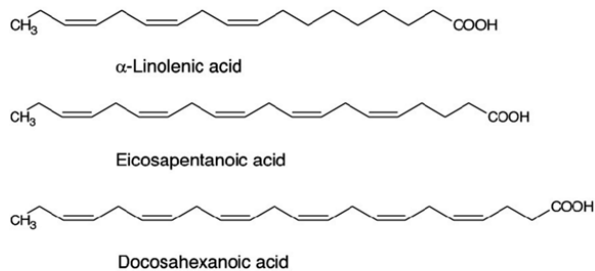
phenols and triterpenes [7]. In olive oil, triacylglycerols is the most common monounsaturated fatty acids (oleic acid), together with balanced ratio of saturated and polyunsaturated fatty acids, mainly linoleic acid. Among the composition of the total fatty acid, monounsaturated fatty acids, saturated fatty acids and polyunsaturated fatty acids are 56–87%, 8–25% and 8–22%, respectively. Polyunsaturated fatty acids are known as essential fatty acids. Those are linoleic acid (18:2, ω -6) in an amount of 3.5–21% and α -linolenic acid (18:3, ω -3) in an amount up to 0.9% [4, 5]. Refined olive oil is prepared from virgin oil by bleaching, degumming, deodorization, neutralization and winterization to change certain characteristics without altering initial glyceridic composition. Different types of ω -6 and ω -3 fatty acids, present in olive oil is represented in Fig. 1.

The ratio ω -6/ ω -3 in olive oil is highly satisfied, since the World Health Organization (WHO) has recommended this ratio to be within 5:1 to 10:1 [7, 8]. ω -3 and ω -6 fatty acids play an important role in development of cell membrane, regulate fluidity of cell membrane and activities of precursor molecules of many physiological elements, those are involved in controlling inflammatory reactions, blood pressure, mortal cardiac diseases and cancer [9].

In addition, total content of antioxidants (phenols) in olive oil is abundant (~500–1000 mg/kg) compared to other edible vegetable oils [10]. Different types of polyphenols present in olive oil are represented in Fig. 2 [11].

Antioxidants are substances that prevent or slow down

ω -3 fatty acids



ω -6 fatty acids

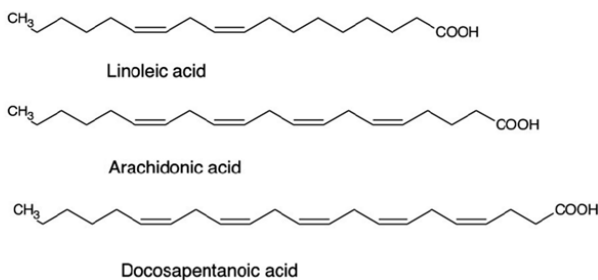


Fig. 1 Different types of ω -3 and ω -6 fatty acids in olive oil (self-developed, concept was adopted from Šarolić et al. [7])

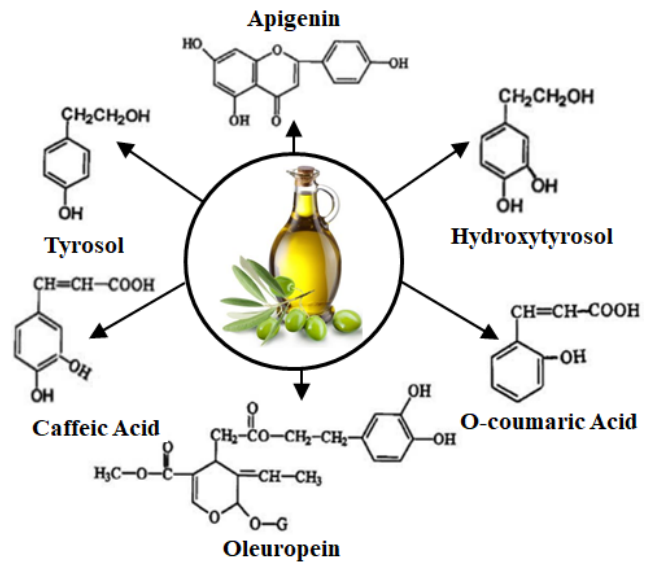


Fig. 2 Different types of polyphenols present in olive oil (self-developed, concept was adopted from Dimitrios [11])

the process of oxidation in the foods, biopharmaceuticals and cells within the body. The considerable amount of phenolic compounds, such as hydroxytyrosol and oleuropein are responsible for the unique taste and high stability of olive oil during storage and cooking [7]. In olive oil, concentration of vitamin E (tocopherols) and vitamin K (phytonadione) are abundant. Tocopherols are methyl-substituted chromanols with a three-isoprene moiety in the side chain. Other tocopherols, such as α -, β -, γ -, and δ -tocopherols differ from one another by the number and position of methyl groups in the phenolic part of the chromane (benzodihydropyran) ring. The α -homologue contains three methyl groups. The β and γ homologues are dimethylated positional isomers. δ -tocopherol is monomethylated. They play an effective role in the inhibition of lipid oxidation in foods and biological systems [12]. Chemically, the vitamin K family comprises 2-methyl-1,4-naphthoquinone (3-) derivatives and includes two natural vitamers, such as vitamin K1 (phyloquinone) and vitamin K2 (menaquinone). They play a significant role in blood clotting, bone metabolism, level of calcium in blood and absorption of vitamin D in body [13].

However, olive oil is enriched with antioxidant, often due to oxidation of fatty acid, sensory and nutritional properties of olive oil are altered [14]. Oxidation of fatty acids leads to the formation of hydroperoxides carboxylic acids, aldehydes, ketones, and short chain alkenes and alkanes. They are responsible to reduce the shelf life of olive oil and consequently, unpleasant taste and odor are generated [10]. One of the solutions to preserve the functional values of

olive oil is its microencapsulation. It prevents the oxidation and increases the shelf life of olive oil [15].

In this review article, information about different technologies of the microencapsulation of olive oil and biochemical characteristics of the microcapsule are discussed. In later exercise, applications of microencapsulated olive oil in food, cosmetic and biopharmaceutical industries are represented.

2 Microencapsulation

Microencapsulation is an emerging technology, which is used to protect bioactive compounds within capsule and control their release in environment. In this process, a small droplet of liquid or solid particles are surrounded by coating within a thin film, known as a wall material or matrix [16–18]. Different techniques have been adopted for the microencapsulation of food grade bioactive compounds. They can be classified into three categories. Those are herein:

1. physical methods: spray drying, lyophilization, supercritical encapsulation and solvent evaporation
2. physico-chemical methods: coacervation, ionic gelation, and molecular inclusion
3. chemical methods: interfacial polymerization and molecular inclusion complexation [19].

For the microencapsulation of olive oil, first step is the preparation of aqueous emulsion of olive oil with matrix. Subsequently, dehydration of emulsion by spray drying or freeze drying or complex coacervation. Extrusion can be also used for microencapsulation of olive oil.

2.1 Emulsification

Emulsion preparation plays a key role in the encapsulation efficiency. Basically, an emulsion consists of at least two immiscible liquids (hydrophilic and hydrophobic). Here one of the liquids being dispersed as small spherical droplets into other [16, 18, 20]. Emulsion instabilities could be expressed either by flocculation, a reversible aggregation of droplets or by coalescence, an irreversible fusion of droplets [21]. To maintain the stability of emulsion, and avoid the coalescence and flocculation of droplets, one or more surface active agents (emulsifiers) are generally used [22]. The emulsion stability is controlled by many factors, such as ratio of oil and water, and presence of emulsifier [23]. Technologies to prepare the emulsion, can be classified into two categories, such as conventional and emerging. Conventional methods rely on stirring equipment, colloid mill, homogenizer and ultrasonic or micro-fluidizer. These technologies are high

energy consuming, since they utilize a strong shearing stress, which may result in coalescence of the dispersed phase. Emulsion prepared through conventional technologies may be polydispersed. Unfortunately, it is difficult to maintain the uniform size of droplet. Emulsion preparation through emerging technologies does not consume significant external thermal or mechanical energy. Therefore, they may be considered as low energy consuming technologies. Emulsification of two immiscible liquids can be prepared by controlling phase inversion temperature, membrane emulsification and spontaneous way [24].

In many cases, biological or chemical emulsifier is used to stabilize emulsion as well as increase the efficiency of emulsion [25, 26].

2.1.1 Emulsifier

Emulsifier is a surface-active agent, also known as "emulgent". It has a great influence to prepare aqueous emulsification of olive oil with matrix. Emulsifiers are amphiphilic by nature with hydrophilic and hydrophobic functional groups in their conformational structure [27]. The emulsifier reduces the interfacial surface tension among hydrophobic and hydrophilic compounds, and makes them miscible [28]. Emulsifiers also offer antimicrobial and antiadhesive properties [29]. Selection of an appropriate emulsifier to prepare stable emulsion is one of the important efforts to formulate emulsion-based product. Furthermore, to find out the suitable concentration of selected emulsifier to prepare stable emulsion is considerable important issue. The hydrophile-lipophile balance and concentration of emulsifier influence the stability of the emulsion and encapsulation efficiency [25]. As emulsification process is a considerable important issue to prepare microcapsule, different emulsifiers, such as lecithin, saponins, Tweens, Spans are commonly used in food, cosmetic and biopharmaceutical industries [30]. For the preparation of olive oil microcapsule, emulsifier lecithin [15] (Fig. 3(A)) and tween 20 [31] (Fig. 3(B)) have been used. Often novel or improved functional activities (enhanced nutritional property, flavor and improved texture) can be obtained using mixture of emulsifiers instead of using single emulsifier [30]. Mechanism of olive oil-water emulsion in presence of emulsifier is represented in Fig. 3(C). During the emulsification process, the hydrophilic group of emulsifier binds with water or the wall material and the hydrophobic group binds with the olive oil [28].

2.1.2 Wall material (matrix)

For microencapsulation of any bioactive compound, selection of a suitable coating material, basically a film-forming

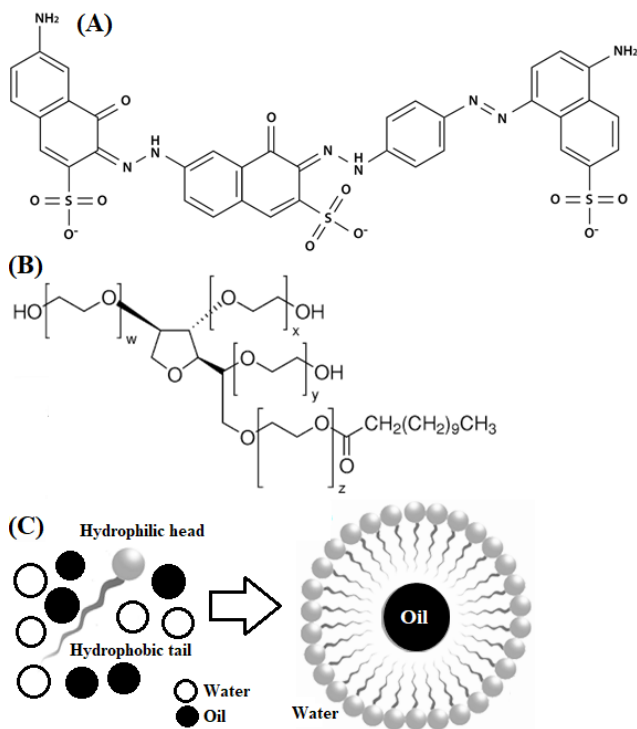


Fig. 3 Emulsifier: Soya lecithin (A); Tween 20 (B); Mechanism of oil-water emulsion in presence of emulsifier (C); (self-developed, concept was adopted from Kinyanjui et al. [27] and Dickinson [28])

agent or matrix or wall material is an important task [32]. Wide variety of natural and synthetic biopolymers are used for microcapsulation of olive oil. It has been reported that the size and shape of microcapsule depend on characteristics of wall material, method and unit operation [3]. Wall material could act as a barrier and it may protect the encapsulated bioactive compound against oxygen, water, light and contact with other ingredients. Furthermore, characteristics of the wall material influences the controlled release of encapsulated bioactive compound to environment [15]. Criteria to select wall material for microencapsulation purpose are soluble in water, a tendency to form a fine and dense network during drying, high glass transition temperature of the oil and matrix to avoid stickiness of microcapsule, and resist the leakage of oil during dehydration or drying [33, 34]. There is no wall material can meet all the mentioned properties. Often combination of different wall materials have been used to prepare microcapsule [32, 35]. Several wall materials, such as gelatin [36, 37], arabic gum [36, 38], sodium caseinate [15], maltodextrin, carboxymethyl cellulose [15, 38], sodium alginate [37, 39], whey protein isolate [31], soy protein isolate, pea protein isolate, defatted milk powder and octenylsuccinic anhydride-modified starch [40] and purple potato starch [41] are used for encapsulation of olive oil.

2.2 Technologies to prepare olive oil microcapsule

To prepare microcapsule of olive oil, several drying technologies to dehydrate the emulsion have been used. These are spray drying [16, 19, 42], freeze drying or lyophilization [19, 42, 43] and coacervation [17, 19, 37, 44]. Furthermore, extrusion have been used for microencapsulation of olive oil [17, 44, 45]. Principles, advantages and disadvantages of mentioned unit operations are mentioned in Table 1.

2.2.1 Spray drying

In several decades, spray-drying has been successfully used in the food industry to prepare microcapsule. The first attempt was to encapsulate flavor using gum acacia as wall material [46]. Consequently, different types of oils were successfully encapsulated using this technique [33, 47, 48]. Its application to formulate cosmetics [47], pharmaceuticals [26] and pesticides [49] have also been published. Preparation of microcapsule by spray drying process involves some steps. The emulsion, prepared by olive oil and aqueous solution of matrix is transferred to nozzle of spray dryer. Due to high heat, phase of wall material is changed, and a layer is created on the surface of droplet of olive oil [16, 34]. Wall materials, such as polysaccharides (alginate, carboxymethylcellulose, arabic gum, maltodextrin, hydrophobically modified starch) and proteins (whey protein, soy protein, sodium caseinate, gelatin) are used to prepare microcapsule by spray drying technique [31, 36, 40]. It has been reported that the size of the microcapsule, prepared by spray drying process ranges within 10–400 μm [50]. The particle size of microcapsule is influenced by the type of atomizer, such as centrifugal wheel atomizer and spray pressure nozzle. If the spray pressure nozzle is used, the particle size of spray-dried product is increased with increase of the nozzle orifice diameter and decreased by the atomization pressure. When the centrifugal wheel atomizer is used, larger wheel diameter and speed provide a smaller size of the particle [32, 50]. Furthermore, different process parameters in emulsion preparation and drying process influence the particle size of microcapsule. Microencapsulation efficiency is reduced with larger oil droplet in emulsion. In the emulsion, viscosity is directly proportional to the droplet size and inversely proportional to the emulsion stability [33]. The particle size of microcapsule increases with the increase in the emulsion flow in spray drying process. In spray dryer, high inlet air temperature and low difference between inlet and outlet air temperatures produce slightly larger particle [32]. In practice, particle size of microcapsule is controlled to some

Table 1 Microencapsulation techniques: principles, steps, advantages and disadvantages

Process	Principle	Steps	Advantages	Disadvantages	Ref.
Spray drying	Due to high heat, the water content is evaporated. Subsequently, due to high heat, the phase of the matrix is altered and solidification of the matrix takes place around the bioactive compound.	1. Preparation of the dispersion or emulsion. 2. Transfer the emulsion into the nozzle for drying.	1. Rapid 2. Continuous operation 3. Simple 4. Economic 5. Reproducible 6. Easy to scale up	1. Limited number of good water soluble wall materials are available. 2. Difficult to control the size and shape of particle. 3. Lower oxidative stability of microcapsules due to the high temperature during drying. 4. Loss of particle in the drying vessel.	[16, 19, 42]
Freeze drying or Lyophilization	Reducing the surrounding pressure. Providing heat to emulsion to sublimate the frozen water. Solid frozen water is transferred to gas phase.	1. Freezing 2. Sublimation (primary drying) 3. Desorption (secondary drying) 4. Storage	1. Low operating temperature 2. Absence of oxidizing atmosphere (air) 3. Prolonged and superior quality product	1. Long process time (more than 20 hours) 2. High capital cost 3. High operating costs 4. Difficult to control the distribution of particle size.	[19, 42, 43]
Coacervation	Liquid – liquid phase separation of a single or a mixture of two oppositely charged polymers in aqueous solution triggered by electrostatic interactions, hydrogen bonding, hydrophobic interactions, polarization-induced attractive interactions as well as chemical or enzymatic cross-linking agent.	1. Formation of three immiscible chemical phases. 2. Deposition of the coating 3. Solidification of the coating	1. High loading capacity 2. Low temperature 3. Reduced thermal degradation 4. Compatibility for control release of bioactive	1. High cost of the particle isolation 2. Complex technique	[17, 19, 37, 44]
Extrusion	Mixing of molten carrier with oil and allow the emulsion to pass through a die or nozzle at high pressure. Molten carrier creates a thin film around bioactive compound at ambient temperature and within cross-linking agent.	1. Preparation of molten matrix 2. Dispersion of core into molten polymer 3. Cooling or passing of core-coat mixture through dehydrating liquid.	1. Impermeability to oxygen 2. Very long shelf life of the encapsulated compound. 3. Good barrier properties of the matrix 4. Low surface oil	1. Expensive (double than spray drying) 2. High shear force is generated using screw extruders at high pressure which affects the stability of core material.	[17, 44, 45]

extent based on the mentioned parameters. Schematic diagram of spray dryer is represented in Fig. 4.

2.2.2 Freeze drying

Freeze-drying is also known as lyophilization or cryodesiccation. It is popularly used in food and biopharmaceutical industries for the dehydration of heat-sensitive bioactive compounds, including olive oil and aromas. Freeze drying process controls the moisture content in the final food product. Chances of thermal deterioration of bioactive compound are less in case of lyophilization process. Therefore, food products, produced by this technology provide a better organoleptic property [44]. Freeze dryer is quite expensive compared to spray dryer. Emulsion of oil and water is frozen between $-90\text{ }^{\circ}\text{C}$ and $-40\text{ }^{\circ}\text{C}$. In this process, the reduction of surrounding pressure takes place

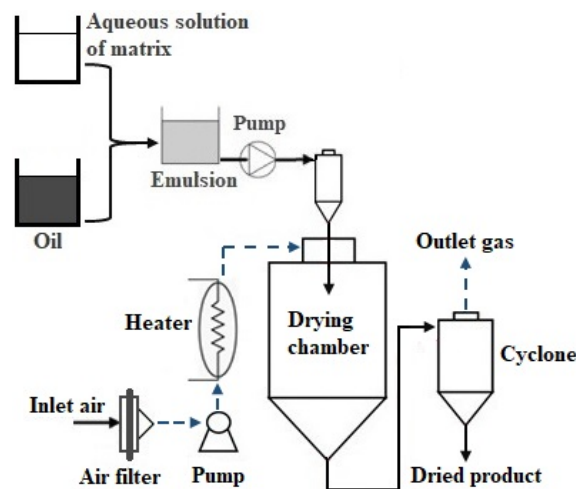


Fig. 4 Schematic representation of spray drying process (self-developed, concept was adopted from Fang and Bhandari [43])

and enough heating to emulsion is applied to allow the frozen water to sublime from the solid state to vapor state. Therefore, in this process, transformation of water from a solid phase to vapor phase directly takes place at a minimal operational temperature. Freezing of emulsion with faster rate may lead to aggregation of the freeze-drying products [16]. Therefore, it is difficult to control the particle size of microcapsule during fridge drying. After freeze drying, dried material is crushed into fine powder [19] and subsequently, sieving may consider to maintain the particle size of microcapsule. In this process, the properties of microcapsules are influenced by the system pressure and temperature. In addition, the operational time of drying is important to achieve a stable moisture content in the dried powder [50]. Wall materials, such as maltodextrin, carboxymethyl cellulose and sodium caseinate are used to prepare olive oil microcapsule by freeze drying process [15]. Depending on process parameters, size of the microcapsule, prepared by freeze drying process ranges within 20–5000 μm [50]. Schematic diagram of freeze dryer is represented in Fig. 5.

2.2.3 Coacervation

Coacervation is generally defined as a liquid – liquid phase separation of a single or a mixture of two oppositely charged polymers in aqueous solution. In this process, application of cross-linking agent including glutaraldehyde or transglutaminase is noteworthy. Among two phases, concentration of polymer is abundant in coacervate phase, whereas concentration of polymer is poor in equilibrium solution [19]. This process could be either simple or complex. The simple process involves only one

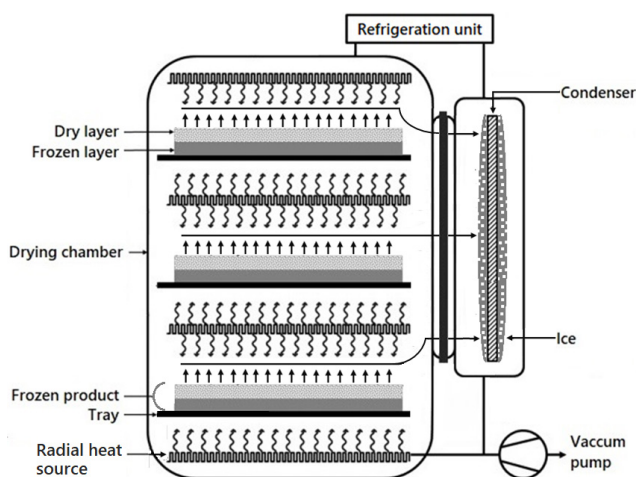


Fig. 5 Schematic representation of freeze drying process (self-developed, concept was adopted from Fang and Bhandari [43])

type of polymer with addition of hydrophilic agent to the colloidal solution. Meanwhile, the complex process involves the interaction of two or more different types of polymers [44, 45]. In this process, oil is usually dispersed in polymer in aqueous/ buffer solution and subsequently, due to pH adjustment, polymer turns to coacervate and form a coating over oil droplets. The next step is cooling and encapsulate the oil within matrix [51]. Several wall materials have been used in simple coacervation process. Those are gelatin, alginate, chitosan, glucan and cellulose derivative [19]. For complex coacervation of omega-3 oil gelatin or whey proteins and oppositely charged gum arabic, sodium polyphosphate or carboxymethylcellulose have been used [37]. Size of the microcapsule, prepared by coacervation process ranges within 2–500 μm [52]. The particle size of microcapsule can be controlled by controlling the temperature, speed of stirring, viscosity of emulsion, concentration and type of polymer, and amount of emulsifier [18]. As example, larger size of microcapsule is produced due to high concentration of polymer. Contradictorily, lower size of microcapsule is produced due to high stirrer speed [52]. Schematic diagram of coacervation process is represented in Fig. 6.

2.2.4 Extrusion

Extrusion technique has been exclusively used for microencapsulation of oil in a carbohydrate matrix [39]. Extrusion technology, used for microencapsulation of oil can be classified in 3 categories, such as melt injection, melt-extrusion and centrifugal extrusion. The principals of melt extrusion and melt injection are similar. In melt extrusion, the driving force to prepare the matrix/wall is a rotating screw without hardening bath, whereas,

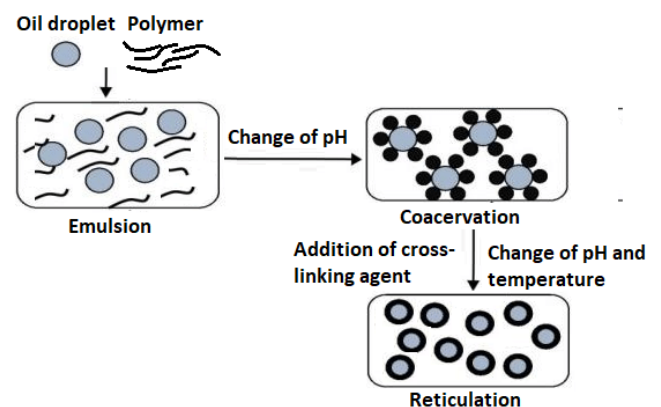


Fig. 6 Schematic representation of coacervation process (self-developed, concept was adopted from Rutz et al. [51])

pressure is a driving force in melt injection process [16]. Centrifugal extrusion is most common than others. It is performed with low temperature comparing to spray drying method [44]. In this process, heated aqueous polymer solution flows through the outer tube and oil flows through the inner tube and finally both two fluids are discharged into a moving stream [45]. For microencapsulation of olive oil by extrusion process, glutaraldehyde [37] and calcium alginate [39] were successfully used. Gelatin, sodium alginate, carraghenan, starches, cellulose derivatives, gum acacia and polyethylene glycol can be used for coating by extrusion process [17]. Size of the microcapsule, prepared by coacervation process ranges within 150–2000 μm [44]. The particle size of microcapsule, produced by extrusion process can be controlled by the diameter of hole in nozzle, external force in nozzle for detachment and flow rate of oil and wall material. Under fixed operating parameters in extrusion process, microcapsule with similar diameter can be produced [45]. Schematic representation of extrusion process is represented in Fig. 7 [53].

3 Characterisation of microencapsulated olive oil

Physical and biochemical characteristics of olive oil microcapsule can be represented by particle size, particle morphology, colour, moisture content, water activity, oxidative stability, encapsulation efficiency (EE) and release of bioactive compounds from the matrix [3]. Characteristics of olive oil microcapsule depend on several factors, such

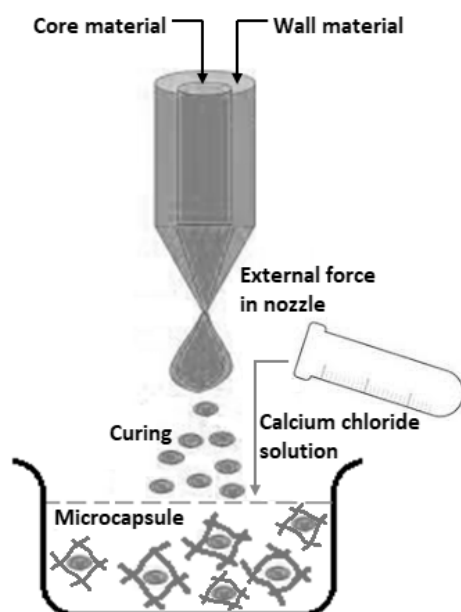


Fig. 7 Schematic representation of extrusion process (self-developed, concept was adopted from Risch [53])

as wall material, emulsifier, ratio of oil and wall material, and encapsulation technique [36]. EE, one of the major characteristics is generally estimated by measuring total oil by destructive method and surface oil. Often, high-performance liquid chromatography (HPLC) or gas chromatography (GC) [15] is adopted for this purpose. Fourier transform infrared (FTIR) spectroscopy is used to understand the modulation of functional groups of fatty acids of oil, matrix and emulsifier in microcapsule. Differential scanning calorimetry (DSC) and thermogravimetric analyzer (TGA) are used to understand the changes of phase and mass of wall material, oil, emulsifier and microcapsule, accordingly. DSC curve is produced based on heat flow versus temperature or time, and TGA curve is produced based on change of mass versus temperature or time [37, 38, 41]. The mean particle size and their distribution are generally evaluated by the dynamic light scattering analytical instrument [40]. Particle morphology, such as surface characteristics, dispersed or agglomeration of particles and surface functionalization of microcapsule is determined by the Scanning Electron Microscopy (SEM) [3, 31]. Zeta potential (ζ -potential) is the electrokinetic potential of solute in colloidal dispersion, which reflects the stability of microcapsule. To understand the zeta potential is an important issue because it represents the fate of microcapsule in food matrix or in intestinal tract. It is measured by the zeta potential analyzer [3]. The moisture content influences the shelf life of the microcapsule and it is measured by the evaporation of water in a hot air oven moisture analyzer [3]. Evaluating of the oxidative stability of oil is a considerable important factor. It is measured by determining the peroxide value, antioxidant activity by 2,2'-azinobis 3-ethylbenzothiazoline-6-sulfonic acid (ABTS) radical scavenging assay [15]. The shelf life of the microencapsulated olive oil can be determined by using accelerated oxidation tests, such as rancimat assay, oxidative stability index OSI [36] and absorbance constants, such as K232 and K270 [15]. K232 represents the average oxidation rate of the components of olive oil and K270 represents the percentage reduction of olive oil resistance from oxidation. Those are measured by the wavelength 232 nm and 270 nm, respectively. The higher values of them represents the poor quality of fat [15]. Summarized information about physical and biochemical characteristics of olive oil microcapsule, prepared by different technologies are represented in Table 2.

Table 2 Process conditions for producing olive oil microcapsule and their characteristics

Process	Wall material	Emulsifier	Cross-linker	Results	Ref.	
Spray drying	A: Gelatin + Gum Arabic + Maltodextrin (MD) B: Sodium caseinate (SC) + Lactose C: SC + MD D: MD + modified starch	–	–	Encapsulation efficiency (EE)	A 42.35%	
					B 52.98%	
					C 38.52%	
					D 33.43%	
				Encapsulation yield (EY)	A 51.20%	
					B 49.49%	
					C 51.21%	
					D 33.44%	
Freeze drying	A: SC + MD B: Carboxymethyl-cellulose (CMC) + MD	Lecithin	–	EE	A 36.90%	
					B 69.09%	
				EY	A 97.67%	
					B 99.79%	
Extrusion	Sodium alginate	–	Calcium chloride	EE 60.6%. The encapsulated olive oil had a peroxide value PV < 14 meq/kg, p-anisidine value p-AV < 2.5 and free fatty acid FFA content < 0.14%, indicating acceptable oil quality.	[39]	
Complex coacervation + Freeze drying	Gelatin A + Sodium alginate	–	Glutaraldehyde	EE 89.37%. Loading capacity (LC) 187.79%. Maximum coacervation occurred when gelatin to sodium alginate ratio was 3.5:1, glutaraldehyde concentration 1.25 mmol.	[37]	
Spray drying	MD	Tween 20	–	EE 69.07%, when concentration of wall material MD and emulsifier are 99% and 1%, respectively.	[31]	
		Soy protein isolate (SPI)		EE		
		Pea protein isolate (PPI)		SPI	87%	
		Defatted milk powder		PPI	82.5%	
Spray drying	MD		–	Defatted milk powder	77.5%	
		Octenylsuccinic anhydride-modified starch (OSA)		OSA	88%	
Porous starch technique: drying under vacuum	Purple Potato starch	–	–	Microencapsulation remarkably improved the UV- or heat- stability, as well as the in vitro bio- accessibility of CoQ10. Improvement of the water solubility and bioavailability of CoQ10.		
				Loading ratio efficiency 29 % when oil to wall ratio is 4:1 Peroxide value PV 8 mmol/Kg	[41]	
Freeze drying	A: MD + CMC B: Alginate (ALG)+ (MD) C: 12.5 g/100 g MD + 7.5 g/100 g	–	–	Particle size	A 81.4 μm	
					B 161 μm	
					C 41.3 μm	
					D 14.8 μm	
		GA Gum Arabic			Glass transition temperature (Tg)	A –
						B –
		D: 10 g/100 g MD + 8.5 g/ 100 g GA				C 146.60 °C
						D 147.54 °C

4 Applications of microencapsulated olive oil

Microencapsulated olive oil has been used in food, pharmaceutical and cosmetic formulations. In subsequent section, information is provided in comprehensive way.

4.1 Foods

Microencapsulated olive oil was used in food industry for many reasons. For general wellbeing, popularity and demand of antioxidant-enriched food catapulted to wide range of communities [16]. Antioxidant enriched foods not only reduce the risks of metabolic dysfunction, but its contribution to provide stability of nutrients against oxidative deterioration in food matrix [37] and preserve different sensory parameters [39]. Recently, oxidative stability of spray dried powder (microcapsule) containing fish oil and extra virgin olive oil blend (1:1 weight ratio), using sugar beet pectin as wall material has been investigated. It has been reported that the addition of olive oil into the formulation can improve the oxidative stability of microencapsulated fish oil and thereby prolong the shelf life of formulation [54]. Presently, ketogenic diet has been received lots of attention. Triacylglycerol in ketogenic diet converts to ketone bodies in the hepatocyte mitochondria (ketogenesis). Subsequently, these ketone bodies provide energy (ATP) through ketolysis in heart and muscle cells. Presence of polyunsaturated fatty acids, such as ω -3 and ω -6 fatty acids in olive oil, its importance in formulation of ketogenic diet is significant [55]. Due to fashionable organoleptic property of olive oil, its importance in cooking recipe is well known from past [56]. Emulsion of olive oil with lemon juice at the ratio (1:1) was microencapsulated by freeze-drying process and used successfully in instant salad sauce [38]. Application of encapsulated olive oil in yogurt and spread cheese has been also reported [57].

4.2 Pharmaceuticals

From old age, application of olive oil was not limited within food recipes. Olive oil has been used as a pharmaceutical because it is considered as safe, biocompatible and non-toxic [58]. In the 19th century, olive oil was administered as laxative and to treat poisoning. It was used in combination with fats and resins to develop skin ointment. Additionally, it could be administered by mouth, for the treatment of an inflammation of the intestinal tube, colic, diarrhea and disparity [59]. Due to the presence of different bioactive compounds, such as polyunsaturated fatty acids, vitamins and antioxidants with unique biochemical properties, olive oil has a great role in formulation of

pharmaceuticals [60]. In pharmaceutical industry, encapsulated olive oil are used as a therapeutics to modulate the oxidative stress that is related to cardiovascular diseases, arteriosclerosis and cancer [60]. Coenzyme Q10 (CoQ10) is a hydrophobic compound with a high molecular weight, resulting the lower oral bioavailability. Microcapsule of olive oil with CoQ10 has been developed by combination of emulsification and drying techniques in sequential way for elderly individuals as oral food supplement due to their health consideration [40]. Polar phenolic compounds in olive oil, mainly hydroxytyrosol and its derivatives offer unique biological activities. It has been proven that their dietary intake reduces the risk of cardiovascular disease and cancer. Scavenging activity of these compounds against superoxide anion, hydrogen peroxide and reactive oxygen species has been demonstrated [11].

4.3 Cosmetics

At end of the 19th century, olive oil started to be used within cosmetics in Mediterranean countries. As example, olive oil was used in hair care and to counter wrinkles in Egyptian culture. The first cold cream was developed by olive oil, bee wax and water in Greece. In Greek culture, olive oil was used to highlight the esthetic perfection of the body of athletes and to prepare them through thermal massage [59]. Several phenolic compounds, such as hydroxytyrosol, catechin, rutin, verbascoside, luteolin and oleuropein in olive oil act as an antioxidant. Their successful implementation in cosmetics have been proven [61]. When cosmetics, enriched with antioxidant are applied into the skin, they enter to the outermost layer of skin, i.e., epidermis, which is mostly composed of keratinocytes. In cosmetic industry, olive oil is largely used due to their antioxidant, nourishing and moisturizing properties [62]. Antioxidant protects the keratinocytes from oxidative damage, and nourish cells and tissues [63]. Vitamin E in olive oil protects skin from free radicals, responsible for the aging of skin [64]. In combination with vitamin A, vitamin E stimulates cell regeneration. It is considered as useful remedy against wrinkles and is also applied in treatment to prevent stretch marks [8, 59]. Presently, microcapsule of olive oil has been applied into the cosmetics with the same aid [18, 58, 63]. In some cases, visible microcapsules are intentionally added in skin and hair creams, shower soaps and household cleaners to make the product more visually attractive [65]. Microencapsulated oil is also found in body deodorants and perfumes [60].

5 Conclusion

For a long time, olive oil has been received attention due to the presence of different bioactive compounds, such as polyunsaturated fatty acids (ω -3 and ω -6 fattyacids), vitamins and phenolic antioxidants with unique biochemical properties. Microencapsulation of olive oil is an unique approach to conserve the biochemical properties of bioactive compounds within olive oil from oxidation and change of environmental condition. As a result, quality and biological activity of olive oil are not deteriorated in the food matrix during processing, cooking and storage. Therefore, several applications of microencapsulated olive oil in food, pharmaceutical and cosmetic industries have been received high status. In this review, information about different techniques to prepare olive oil microcapsule, characterization of olive oil microcapsule, and application of encapsulated olive oil in food, pharmaceutical and cosmetic industries are represented in comprehensive way. Selection of method to

prepare microcapsule depends on according to situation and product interest. Furthermore, different process parameters influence the characteristics of olive oil microcapsule. It is shown that microcapsule, produced by extrusion technique has homogeneous diameter. Presently, olive oil microcapsule (Extra Virgin Olive Oil Cold-Pressed 1000 Milligrams 120 Sgels) is produced by Swanson Ltd, USA and available in market. It is expected that the present review may receive attention of different research communities, food and pharmaceutical industries.

Acknowledgement

Authors acknowledge the support from the European Union project – EFOP-3.6.3-VEKOP-16-2017-00005. A. Nath acknowledges hungarian state postdoctoral scholarship. D. Chaabane and A. Yakhane acknowledge the Doctoral School of Food Science, Hungarian University of Agriculture and Life Sciences, Hungary.

References

- [1] Gunstone, F. D. "Production and Trade of Vegetable Oils", In: Gunstone, F. D. (ed.) *Vegetable Oils in Food Technology: Composition, Properties and Uses*, Blackwell, Oxford, UK, 2011, pp. 1–24.
<https://doi.org/10.1002/9781444339925.ch1>
- [2] Espínola, F., Vidal, A. M., Espínola, J. M., Moya, M. "Processing Effect and Characterization of Olive Oils from Spanish Wild Olive Trees (*Olea europaea* var. *sylvestris*)", *Molecules*, 26(5), Article number: 1304, 2021.
<https://doi.org/10.3390/molecules26051304>
- [3] Onsaard, E., Onsaard, W. "Microencapsulated Vegetable Oil Powder", In: Salaün, F. (ed.) *Microencapsulation: Processes, Technologies and Industrial Applications*, IntechOpen, London, UK, 2019, pp. 1–19.
<https://doi.org/10.5772/intechopen.85351>
- [4] Dahl, W. J., Tandlich, M. A., England, J. "Health Benefits of Olive Oil and Olive Extracts", *EDIS*, 2016(4), Article number: FSHN16-4., 2020. [online] Available at: <https://edis.ifas.ufl.edu/publication/FS282> [Accessed: 20 November 2021]
- [5] Gaforio, J. J., Visioli, F., Alarcón-de-la-Lastra, C., Castañer, O., Delgado-Rodríguez, M., Fitó, M., Hernández, A. F., ..., Tsatsakis, A. M. "Virgin Olive Oil and Health: Summary of the III International Conference on Virgin Olive Oil and Health Consensus Report, JAEN (Spain) 2018", *Nutrients*, 11(9), Article number: 2039, 2019.
<https://doi.org/10.3390/nu11092039>
- [6] Boskou, D. "Olive Oil", In: Simopoulos, A. P., Visioli, F. (eds.) *More on Mediterranean Diets, World Review of Nutrition and Dietetics*, Basel, Switzerland, 2007. pp. 180–210.
<https://doi.org/10.1159/000097916>
- [7] Šarolić, M., Gugić, M., Marijanović, Z., Šuste, M. "Virgin olive oil and nutrition", *Food in health and disease, scientific-professional journal of nutrition and dietetics*, 3(1), pp. 38–43, 2014. [online] Available at: <https://hrcak.srce.hr/126239> [Accessed: 20 November 2021]
- [8] Viola, P., Viola, M. "Virgin olive oil as a fundamental nutritional component and skin protector", *Clinics in Dermatology*, 27(2), pp. 159–165, 2009.
<https://doi.org/10.1016/j.clindermatol.2008.01.008>
- [9] de la Lastra, C., Barranco, M. D., Motilva, V., Herreras, J. "Mediterranean Diet and Health Biological Importance of Olive Oil", *Current Pharmaceutical Design*, 7(10), pp. 933–950, 2001.
<https://doi.org/10.2174/1381612013397654>
- [10] Koidis, A., Boskou, D. "Chapter 32 - Virgin Olive Oil: Losses of Antioxidant Polar Phenolic Compounds due to Storage, Packaging, and Culinary Uses", In: Preedy, V. (ed.) *Processing and Impact on Active Components in Food*, Academic Press, London, UK, 2015, pp. 267–274.
<https://doi.org/10.1016/B978-0-12-404699-3.00032-9>
- [11] Dimitrios, B. "Sources of natural phenolic antioxidants", *Trends in Food Science & Technology*, 17(9), pp. 505–512, 2006.
<https://doi.org/10.1016/j.tifs.2006.04.004>
- [12] Psomiadou, E., Tsimidou, M., Boskou, D. "α-Tocopherol Content of Greek Virgin Olive Oils", *Journal of Agricultural and Food Chemistry*, 48(5), pp. 1770–1775, 2000.
<https://doi.org/10.1021/jf990993o>
- [13] Otlés, S., Cagindi, O. "Determination of vitamin K₁ content in olive oil, chard and human plasma by RP-HPLC method with UV–Vis detection", 100(3), pp. 1220–1222, 2007.
<https://doi.org/10.1016/j.foodchem.2005.12.003>

- [14] Aparicio, R., Harwood, J. (eds.) "Handbook of Olive Oil: Analysis and Properties", Springer, Boston, MA, USA, 2013.
<https://doi.org/10.1007/978-1-4614-7777-8>
- [15] Calvo, P., Castaño, Á. L., Lozano, M., González-Gómez, D. "Influence of the microencapsulation on the quality parameters and shelf-life of extra-virgin olive oil encapsulated in the presence of BHT and different capsule wall components", *Food Research International*, 45(1), pp. 256–261, 2012.
<https://doi.org/10.1016/j.foodres.2011.10.036>
- [16] Bakry, A. M., Abbas, S., Ali, B., Majeed, H., Abouelwafa, M. Y., Mousa, A., Liang, L. "Microencapsulation of Oils: A Comprehensive Review of Benefits, Techniques, and Applications", *Comprehensive Reviews in Food Science and Food Safety*, 15(1), pp. 143–182, 2016.
<https://doi.org/10.1111/1541-4337.12179>
- [17] Poshadri, A., Kuna, A. "MICROENCAPSULATION TECHNOLOGY: A REVIEW", *The journal of research ANGRAU*, 38(1), pp. 86–102, 2010. [online] Available at: <https://www.coursehero.com> [Accessed: 20 November 2021]
- [18] Rodríguez, J., Martín, M. J., Ruiz, M. A., Clares, B. "Current encapsulation strategies for bioactive oils: From alimentary to pharmaceutical perspectives", *Food Research International*, 83, pp. 41–59, 2016.
<https://doi.org/10.1016/j.foodres.2016.01.032>
- [19] Ozkan, G., Franco, P., De Marco, I., Xiao, J., Capanoglu, E. "A review of microencapsulation methods for food antioxidants: Principles, advantages, drawbacks and applications", *Food Chemistry*, 272, pp. 494–506, 2019.
<https://doi.org/10.1016/j.foodchem.2018.07.205>
- [20] Fang, Z., Bhandari, B. "Encapsulation of polyphenols - a review", *Trends in Food Science & Technology*, 21(10), pp. 510–523, 2010.
<https://doi.org/10.1016/j.tifs.2010.08.003>
- [21] Aronson, M. P. "The Role of Free Surfactant in Destabilizing Oil-in-Water Emulsions", *Langmuir*, 5(2), pp. 494–501, 1989.
<https://doi.org/10.1021/la00086a036>
- [22] Zanatta, V., Rezzadori, K., Penha, F. M., Zin, G., Lemos-Senna, E., Petrus, J. C. C., Di Luccio, M. "Stability of oil-in-water emulsions produced by membrane emulsification with microporous ceramic membranes", *Journal of Food Engineering*, 195, pp. 73–84, 2017.
<https://doi.org/10.1016/j.jfoodeng.2016.09.025>
- [23] Nakashima, T., Shimizu, M., Kukizaki, M. "Particle control of emulsion by membrane emulsification and its applications", *Advanced Drug Delivery Reviews*, 45(1), pp. 47–56, 2000.
[https://doi.org/10.1016/S0169-409X\(00\)00099-5](https://doi.org/10.1016/S0169-409X(00)00099-5)
- [24] Nazari, M., Mehrnia, M. A., Jooyandeh, H., Barzegar, H. "Preparation and characterization of water in sesame oil micro-emulsion by spontaneous method", *Journal of Food Process Engineering*, 42(4), Article number: e13032, 2019.
<https://doi.org/10.1111/jfpe.13032>
- [25] Yang, X., Li, S., Yan, J., Xia, J., Huang, L., Li, M., Ding, H., Xu, L. "Effect of different combinations of emulsifier and wall materials on physical properties of spray-dried microencapsulated *swida wilsoniana* oil", *Journal of Bioresources and Bioproducts*, 5(1), pp. 44–50, 2020.
<https://doi.org/10.1016/j.jobab.2020.03.005>
- [26] Liu, T. T., Yang, T. S. "Optimization of Emulsification and Microencapsulation of Evening Primrose Oil and Its Oxidative Stability During Storage by Response Surface Methodology", *Journal of Food Quality*, 34, pp. 64–73, 2011.
<https://doi.org/10.1111/j.1745-4557.2010.00358.x>
- [27] Kinyanjui, T., Artz, W. E., Mahungu, S. "EMULSIFIERS| Organic Emulsifiers", In: Caballero, B. (ed.) *Encyclopedia of Food Sciences and Nutrition*, Elsevier, Amsterdam, The Netherlands, 2003, pp. 2070–2077.
<https://doi.org/10.1016/B0-12-227055-X/00401-6>
- [28] Dickinson, E. "Hydrocolloids as emulsifiers and emulsion stabilizers", *Food Hydrocolloids*, 23(6), pp. 1473–1482, 2009.
<https://doi.org/10.1016/j.foodhyd.2008.08.005>
- [29] Nabilah, A., Handayani, S., Setiasih, S., Rahayu, D. U. C., Hudiyono, S. "Emulsifier and antimicrobial activity against *Propionibacterium acnes* and *Staphylococcus epidermidis* of oxidized fatty acid esters from hydrolyzed castor oil", *IOP Conference Series: Materials Science and Engineering*, 833, Article number: 012025, 2019.
<https://doi.org/10.1088/1757-899X/833/1/012025>
- [30] McClements, D. J., Jafari, S. M. "Improving emulsion formation, stability and performance using mixed emulsifiers: A review", *Advances in Colloid and Interface Science*, 251, pp. 55–79, 2018.
<https://doi.org/10.1016/j.cis.2017.12.001>
- [31] Koç, M., Güngör, Ö., Zungur, A., Yalçın, B., Selek, İ., Ertekin, F. K., Ötles, S. "Microencapsulation of Extra Virgin Olive Oil by Spray Drying: Effect of Wall Materials Composition, Process Conditions, and Emulsification Method", *Food and Bioprocess Technology*, 8(2), pp. 301–318, 2015.
<https://doi.org/10.1007/s11947-014-1404-9>
- [32] Jafari, S. M., Assadpoor, E., He, Y., Bhandari, B. "Encapsulation Efficiency of Food Flavours and Oils during Spray Drying", *Drying Technology*, 26(7), pp. 816–835, 2008.
<https://doi.org/10.1080/07373930802135972>
- [33] Bae, E. K., Lee, S. J. "Microencapsulation of avocado oil by spray drying using whey protein and maltodextrin", *Journal of Microencapsulation*, 25(8), pp. 549–560, 2008.
<https://doi.org/10.1080/02652040802075682>
- [34] Gharsallaoui, A., Roudaut, G., Chambin, O., Voilley, A., Saurel, R. "Applications of spray-drying in microencapsulation of food ingredients: An overview", *Food Research International*, 40(9), pp. 1107–1121, 2007.
<https://doi.org/10.1016/j.foodres.2007.07.004>
- [35] Hogan, S. A., McNamee, B. F., O'Riordan, E. D., O'Sullivan, M. "Emulsification and microencapsulation properties of sodium caseinate/carbohydrate blends", *International Dairy Journal*, 11(3), pp. 137–144, 2001.
[https://doi.org/10.1016/S0958-6946\(01\)00091-7](https://doi.org/10.1016/S0958-6946(01)00091-7)
- [36] Calvo, P., Hernández, T., Lozano, M., González-Gómez, D. "Microencapsulation of extra-virgin olive oil by spray-drying: Influence of wall material and olive quality", *European Journal of Lipid Science and Technology*, 112(8), pp. 852–858, 2010.
<https://doi.org/10.1002/ejlt.201000059>

- [37] Devi, N., Hazarika, D., Deka, C., Kakati, D. K. "Study of Complex Coacervation of Gelatin and Sodium Alginate for Microencapsulation of Olive Oil", *Journal of Macromolecular Science, Part A: Pure and Applied Chemistry*, 49(11), pp. 936–945, 2012.
<https://doi.org/10.1080/10601325.2012.722854>
- [38] Silva, K. A., Coelho, M. A. Z., Calado, V. M. A., Rocha-Leão, M. H. M. "Olive oil and lemon salad dressing microencapsulated by freeze-drying", *LWT - Food Science and Technology*, 50(2), pp. 569–574, 2013.
<https://doi.org/10.1016/j.lwt.2012.08.005>
- [39] Sun-Waterhouse, D., Zhou, J., Miskelly, G. M., Wibisono, R., Wadhwa, S. S. "Stability of encapsulated olive oil in the presence of caffeic acid", *Food Chemistry*, 126(3), pp. 1049–1056, 2011.
<https://doi.org/10.1016/j.foodchem.2010.11.124>
- [40] Zhao, X. H., Tang, C. H. "Spray-drying microencapsulation of CoQ₁₀ in olive oil for enhanced water dispersion, stability and bio-accessibility: Influence of type of emulsifiers and/or wall materials", *Food Hydrocolloids*, 61, pp. 20–30, 2016.
<https://doi.org/10.1016/j.foodhyd.2016.04.045>
- [41] Lei, M., Jiang, F. C., Cai, J., Hu, S., Zhou, R., Liu, G., Wang, Y. H., Wang, H. B., He, J. R., Xiong, X. G. "Facile microencapsulation of olive oil in porous starch granules: Fabrication, characterization, and oxidative stability", *International Journal of Biological Macromolecules*, 111, pp. 755–761, 2018.
<https://doi.org/10.1016/j.ijbiomac.2018.01.051>
- [42] Paulo, F., Santos, L. "Deriving valorization of phenolic compounds from olive oil by-products for food applications through microencapsulation approaches: a comprehensive review", *Critical Reviews in Food Science and Nutrition*, 61(6), pp. 920–945, 2021.
<https://doi.org/10.1080/10408398.2020.1748563>
- [43] Fang, Z., Bhandari, B. "4 - Spray drying, freeze drying and related processes for food ingredient and nutraceutical encapsulation", In: Garti, N., McClement, D. J. (eds.) *Encapsulation Technologies and Delivery Systems for Food Ingredients and Nutraceuticals*, Woodhead Publishing, Sawston, UK, 2012, pp. 73–109.
<https://doi.org/10.1533/9780857095909.2.73>
- [44] Desai, K. G. H., Jin Park, H. "Recent Developments in Microencapsulation of Food Ingredients", *Drying Technology*, 23(7), pp. 1361–1394, 2005.
<https://doi.org/10.1081/DRT-200063478>
- [45] Kaushik, P., Dowling, K., Barrow, C. J., Adhikari, B. "Microencapsulation of omega-3 fatty acids: A review of microencapsulation and characterization methods", *Journal of Functional Foods*, 19(B), pp. 868–881, 2015.
<https://doi.org/10.1016/j.jff.2014.06.029>
- [46] Shahidi, F., Han, X. Q. "Encapsulation of food ingredients", *Critical Reviews in Food Science and Nutrition*, 33(6), pp. 501–547, 1993.
<https://doi.org/10.1080/10408399309527645>
- [47] Xu, S., Tang, Z., Liu, H., Wang, M., Sun, J., Song, Z., ..., Yu, J. "Microencapsulation of sea buckthorn (*Hippophae rhamnoides* L.) pulp oil by spray drying", *Food Science & Nutrition*, 8(11), pp. 5785–5797, 2020.
<https://doi.org/10.1002/fsn3.1828>
- [48] Chan, L. W., Lim, L. T., Heng, P. W. S. "Microencapsulation of oils using sodium alginate", *Journal of Microencapsulation*, 17(6), pp. 757–766, 2000.
<https://doi.org/10.1080/02652040050161747>
- [49] López, A., Castro, S., Andina, M. J., Ures, X., Munguía, B., Llabot, J. M., Elder, H., Dellacassa, E., Palma, S., Domínguez, L. "Insecticidal activity of microencapsulated *Schinus molle* essential oil", *Industrial Crops and Products*, 53, pp. 209–216, 2014.
<https://doi.org/10.1016/j.indcrop.2013.12.038>
- [50] Yakhane, A., Labidi, S., Chaabane, D., Tolnay, A., Nath, A., Koris, A., Vatai, G. "Microencapsulation of Flaxseed Oil—State of Art", *Processes*, 9(2), Article number: 295, 2021.
<https://doi.org/10.3390/pr9020295>
- [51] Rutz, J. K., Borges, C. D., Zambiasi, R. C., Crizel-Cardozo, M. M., Kuck, L. S., Noreña, C. P. Z. "Microencapsulation of palm oil by complex coacervation for application in food systems", *Food Chemistry*, 220, pp. 59–66, 2017.
<https://doi.org/10.1016/j.foodchem.2016.09.194>
- [52] Jyothi, N. V. N., Prasanna, P. M., Sakarkar, S. N., Prabha, K. S., Ramaiah, P. S., Srawan, G. Y. "Microencapsulation techniques, factors influencing encapsulation efficiency", *Journal of Microencapsulation*, 27(3), pp. 187–197, 2010.
<https://doi.org/10.3109/02652040903131301>
- [53] Risch, S. J. "Encapsulation of Flavors by Extrusion", In: Risch, S. J., Reineccius, G. A. (eds.) *Flavor Encapsulation*, American Chemical Society, Washington, DC, USA, 1988, pp. 103–109.
<https://doi.org/10.1021/bk-1988-0370.ch011>
- [54] Polavarapu, S., Oliver, C. M., Ajlouni, S., Augustin, M. A. "Physicochemical characterisation and oxidative stability of fish oil and fish oil-extra virgin olive oil microencapsulated by sugar beet pectin", *Food Chemistry*, 127(4), pp. 1694–1705, 2011.
<https://doi.org/10.1016/j.foodchem.2011.02.044>
- [55] Ludwig, D. S. "The Ketogenic Diet: Evidence for Optimism but High-Quality Research Needed", *Journal of Nutrition*, 150(6), pp. 1354–1359, 2020.
<https://doi.org/10.1093/jn/nxz308>
- [56] Moldão-Martins, M., Beirão-da-Costa, S., Neves, C., Cavaleiro, C., Salgueiro, L., Beirão-da-Costa, M. L. "Olive oil flavoured by the essential oils of *Mentha × piperita* and *Thymus mastichina* L.", *Food Quality and Preference*, 15(5), pp. 447–452, 2004.
<https://doi.org/10.1016/j.foodqual.2003.08.001>
- [57] Poirieux, M., Kostov, G., Denkova, R., Shopska, V., Ivanova, M., Balabanova, T., Vlaseva, R. "Optimization of Conditions for Obtaining Alginate/Olive Oil Capsules for Application in Dairy Industry", *Acta Universitatis Cibiniensis. Series E: Food Technology*, 21(1), pp. 11–22, 2017.
<https://doi.org/10.1515/aucft-2017-0002>
- [58] Jos, F. "The Use of Plants in Skin-Care Products, Cosmetics and Fragrances: Past and Present", *Cosmetics*, 5(3), Article number: 50, 2018.
<https://doi.org/10.3390/cosmetics5030050>
- [59] Gorini, I., Iorio, S., Ciliberti, R., Licata, M., Armocida, G. "Olive oil in pharmacological and cosmetic traditions", *Journal of Cosmetic Dermatology*, 18(5), pp. 1575–1579, 2019.
<https://doi.org/10.1111/jocd.12838>

- [60] Martins, E., Poncelet, D., Rodrigues, R. C., Renard, D. "Oil encapsulation techniques using alginate as encapsulating agent: applications and drawbacks", *Journal of Microencapsulation*, 34(8), pp. 754–771, 2017.
<https://doi.org/10.1080/02652048.2017.1403495>
- [61] Kashaninejad, M., Sanz, M. T., Blanco, B., Beltrán, S., Niknam, S. M. "Freeze dried extract from olive leaves: Valorisation, extraction kinetics and extract characterization", *Food and Bioproducts Processing*, 124, pp. 196–207, 2020.
<https://doi.org/10.1016/j.fbp.2020.08.015>
- [62] Badiu, D., Luque, R., Rajendram, R. "Chapter 123 - Effect of Olive Oil on the Skin", In: Preedy, V. R., Waston, R. R. (eds.) *Olives and Olive Oil in Health and Disease Prevention*, Elsevier, London, UK, 2010, pp. 1125–1132.
<https://doi.org/10.1016/B978-0-12-374420-3.00123-6>
- [63] de la Luz Cádiz-Gurrea, M., Pinto, D., Delerue-Matos, C., Rodrigues, F. "Olive Fruit and Leaf Wastes as Bioactive Ingredients for Cosmetics—A Preliminary Study", *Antioxidants*, 10(2), Article number: 245, 2021.
<https://doi.org/10.3390/antiox10020245>
- [64] Danby, S. G., AlEnezi, T., Sultan, A., Lavender, T., Chittock, J., Brown, K., Cork, M. J. "Effect of Olive and Sunflower Seed Oil on the Adult Skin Barrier: Implications for Neonatal Skin Care", *Pediatric Dermatology*, 30(1), pp. 42–50, 2013.
<https://doi.org/10.1111/j.1525-1470.2012.01865.x>
- [65] Barbulova, A., Colucci, G., Apone, F. "New Trends in Cosmetics: By-Products of Plant Origin and Their Potential Use as Cosmetic Active Ingredients", *Cosmetics*, 2(2), pp. 82–92, 2015.
<https://doi.org/10.3390/cosmetics2020082>