CHAPTER

Encapsulation techniques for plant extracts

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4.1 Introduction

The intake of functional foods has been increasing in the daily human diet. This has drawn the interest of researchers to formulate and use bioactive compounds, including plant extract compounds in different food formulations (Comunian, Silva, & Souza, 2021). Efforts to make functional foods have been increased because of the health benefits of these foods. Functional foods are edible products fortified with superior compounds/agents, including essential oils, antioxidants, minerals, vitamins, flavors, and bioactive compounds (Fang & Bhandari, 2010; Granato et al., 2020; Mir, Shah, Ganai, Ahmad, & Gani, 2019).

Plants are widely known as a natural source of numerous bioactive compounds having several biological activities. Plant extracts are complex mixtures of chemical compounds with numerous biological properties and are mostly derived from the different parts of medicinal plants and herbs (Fang & Bhandari, 2010; Muñoz-Shugulí, Vidal, Cantero-López, & Lopez-Polo, 2021). Bioactive compounds, including carotenoids, alkaloids, flavonoids, terpenoids, anthocyanins, polyphenols, saponins, and essential oils, are substances extracted from different plant parts and have numerous health benefits (Jia, Dumont, & Orsat, 2016; Muñoz-Shugulí et al., 2021). Some of these compounds have antioxidant, antiviral, antibacterial, antifungal, anticancer, anti-inflammatory, hypoglycemic, antihypertensive, and immunomodulatory activities (Shishir, Xie, Sun, Zheng, & Chen, 2018).

However, these plant extract compounds are easily susceptible to degradation under adverse factors during processing and storage, and these are sensitive to air, temperature, pH, and humidity (Fang & Bhandari, 2010). Also, bioactive compounds extracted from plants with polar and nonpolar solvents are commonly insoluble or sparingly soluble in water (Akolade, Oloyede, & Onyenekwe, 2017). Furthermore, plant extract compounds are inadequately applied in the novel food formulations because of their chemical instability, low thermal stability, bitter taste, and sensitivity to oxidation (Shishir et al., 2018). Therefore, to maintain the physicochemical and biological properties of plant extract compounds or to improve their sustained release properties and applicability to food formulations, encapsulation is considered a viable alternative.

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Encapsulation is a physicochemical process where an active molecule or compound is trapped into an immiscible substance, which can be either liquid or solid (Rehman et al., 2019). Furthermore, in this technology, a physical barrier is employed to protect and maintain the physicochemical properties, bioavailability, and biological properties of the bioactive compounds against any adverse environmental conditions (Fang & Bhandari, 2010; Muñoz-Shuguĺí et al., 2021). The applications of encapsulation have recently expanded in the food industry since encapsulated bioactive compounds can be protected from processing and storage conditions (Saifullah, Shishir, Ferdowsi, Rahman, & Van Vuong, 2019). Furthermore, encapsulation enhances the stability and biological properties, sustained release properties, and prolonged shelf life of plant extract compounds (Fang & Bhandari, 2010). A wide range of techniques have been established to encapsulate plant extract compounds, including spray drying, spray chilling, freeze drying, coacervation, emulsion, liposome entrapment, and inclusion complexation.

This chapter presents techniques that have recently been employed for encapsulating plant extract compounds, as well as demonstrate recent developments in encapsulation techniques and their application in food industries.

4.2 Encapsulation

Encapsulation is a rapidly growing technique in which molecules are uniquely packed in the form of micro- and nanoparticles and is described as a physicochemical process for entrapping one substance (guest molecule) within another (host molecule) (Mahdavi, Jafari, Ghorbani, & Assadpoor, 2014). In this process, the guest molecules are also labeled as the core molecule, while the host molecules are known as the carrier material, matrix, or wall material (Devi, Sarmah, Khatun, & Maji, 2017). Encapsulation is widely used in food industries to protect and maintain plant extract compounds against processing, and other adverse factors. Encapsulation improves the physicochemical properties, water solubility, bioavailability, biological properties and sustained the release properties of bioactive compounds. Use of encapsulated bioactive compounds instead of free compounds can overcome the drawbacks of bioactive compounds that is, their instability, unpleasant taste, or flavor, as well as expand their physicochemical properties, biological activities, and shelf life (Fang & Bhandari, 2010; Muñoz-Shuguĺí et al., 2021). Therefore, encapsulation contributes by preserving as well as improving the functionality of plant-extracted compounds.

Wall materials (host or carrier materials) are vital for encapsulation and must be selected based on the purpose of encapsulation and the compatibility of the material with the food system. Furthermore, some key features of perfect wall materials are high solubility, low hygroscopy, as well as the ability of developing a highly stable emulsion and providing highly safe and secure environment (Shishir et al., 2018). The most commonly used wall materials for encapsulation in food industries are starch and its starch derivatives, chitosan, gums, phospholipids, soy proteins, milk and whey proteins (Fang & Bhandari, 2010; Wandrey, Bartkowiak, & Harding, 2010).

4.3 Encapsulation techniques

In the food industry, several techniques are used for encapsulating plant extract compounds (Fig. 4.1). Even though there is no standard system of encapsulation, different basic parameters, including core (guest molecule) and carrier (host material) molecular weight, structure, shape, polarity, and encapsulation efficiency, need to be considered before selecting a proper technique; and they are continuously optimized to secure the quality characteristics of diverse core molecules. According to their mechanism, encapsulation techniques are categorized into physical procedures,

FIGURE 4.1

Techniques used for encapsulation of plant extracts.

based on the distribution of emulsion, or dispersion using different mechanical practices (de Moura, Berling, Germer, Alvim, & Hubinger, 2018), and chemical procedures, where a carrier material is formed around a core compound in liquid (Nedovic, Kalusevic, Manojlovic, Levic, & Bugarski, 2011).

4.3.1 Spray drying

Spray drying has been widely used in the food industries for encapsulation and stabilization of plant extract compounds (Fig. 4.2). In spray drying, during atomization of an emulsion, atomized droplets encounter hot gas, leading to micro-particle formation (Gadkari & Balaraman, 2015). Spray drying involves some steps, namely selection of suitable coating material, formulation of emulsion between guest and host materials, and the drying process that affects the morphological characteristics of developed capsules; the encapsulation efficiency, retention rate, and bioactivity of guest molecules are also affected during drying (Gadkari & Balaraman, 2015). Further, the coating material should be hydrophilic because water-based solutions or emulsions are employed in spray drying. In spray drying, carbohydrate molecules including as starch and its derivatives, edible gums, or other substances can be used as coating materials (Fang & Bhandari, 2010)), while hydrophobic

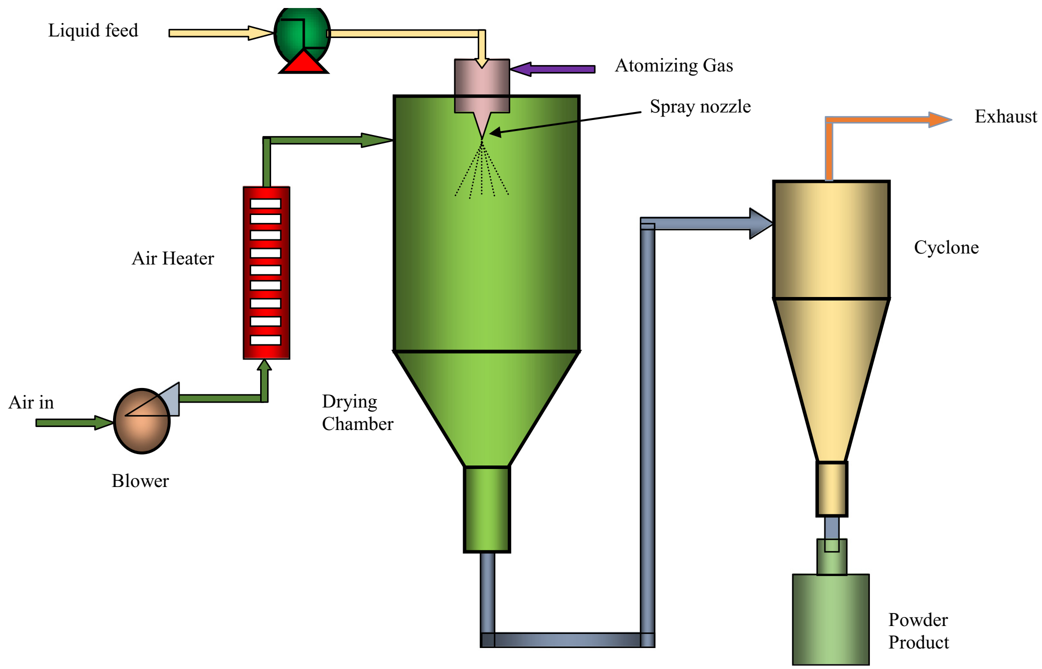

FIGURE 4.2

Schematic diagram showing the spray drying process.

and/or hydrophilic plant extract compounds can be applied as core materials (Desai & Jin Park, 2005). Moreover, nitrogen and air gas are applied to dry the dispersions as they are inert toward the material to be dried.

Spray drying is a low-cost technique for encapsulating plant extract compounds. Initially, a liquid solution comprising a host material and the guest molecule in a solvent is atomized into droplets using compressed gas. Subsequently, heated carrier gas is carried in contact with the atomized dispersion feed through a gas disperser, leading to solvent evaporation. As the solvent swiftly evaporates from the droplet, a micro-particle forms and falls to the bottom of the chamber. The resultant powder is recovered from the exhaust gases using a cyclone separator. It produces good quality particles of size $<40\ \mu m$ (Gadkari & Balaraman, 2015; Zuidam & Heinrich, 2010). The size of the formulated particles is desirable for the sensorial characteristics of final food products.

Besides the advantages of encapsulation, chemical compounds, including polyphenols, flavonoids, carotenoids, saponins, anthocyanins, essential oils, and terpenoids are successfully extracted from the byproducts of food industries, including pomegranate peel, grape pomace, and citrus processing byproducts. Rosemary essential oil was encapsulated using spray drying, with hydrocolloid and maltodextrin protecting the major compounds (Fernandes et al., 2017). The encapsulated essential oil acted as a potent bio-preservative inhibiting the growth of microbes and extending the shelf life of cheese. In another study, Santhalakshmy, Bosco, Francis, and Sabeena (2015) encapsulated jamun fruit juice using spray drying. They used maltodextrin as the wall material to expand the physicochemical properties, and shelf-life of anthocyanins. Sablania, Bosco, Rohilla, and Shah (2018) prepared encapsulated powder from curry leaf extracts by spray drying using different wall materials. These encapsulated powders may be used as functional additives in various food systems because of their antioxidant potential.

4.3.2 Freeze drying

Freeze drying is commonly used for the drying up of all heat-sensitive plant extract compounds. In this process, the material is frozen, the adjacent pressure is decreased, and sufficient heat is maintained to allow the frozen water molecule in the material to transfer clearly from the solid phase to the gas phase (Nedovic et al., 2011). Encapsulation through freeze drying is accomplished when core compounds homogenize in the matrix or carrier solution and then co-lyophilize, typically ensuing in diverse forms (Desai & Jin Park, 2005). This encapsulation process produces high-quality products, does not alter their sensorial characteristics, retains their biological properties, and offers a longer shelf life for core molecules (Tarone, Cazarin, & Junior, 2020). The main drawbacks of freeze drying are long processing time, high energy use, and formation of an open porous structure, which is usually not a very good barrier between core molecule and its storage conditions (Ezhilarasi, Karthik, Chhanwal, & Anandharamakrishnan, 2013).

Among all encapsulation techniques, freeze drying is a superior system for plant extract compounds because of higher encapsulation efficiency, better retention of stability, sustained release properties, and biological activities (Fang & Bhandari, 2010). Through freeze drying, Laine, Kylli, Heinonen, and Jouppila (2008) encapsulated cloudberry extract by using maltodextrin as the wall material. The encapsulated cloudberry extract shown improved protection of polyphenols during processing and storage. Furthermore, Elsebaie and Essa (2018) employed freeze drying to encapsulate bioactive compounds from red onion peels by using soy protein isolates and maltodextrin as wall materials to improve polyphenol stability. Using freeze drying, Reddy, Jung, Son, and Lee (2020) recently encapsulated catechin-rich green tea extract. They used β-cyclodextrin as the wall material to expand the stability and antioxidant activity of catechins.

4.3.3 Spray chilling and spray cooling

Spray chilling and spray cooling are very similar to spray drying, but the air temperature used for drying is different. Spray chilling is a promising encapsulation procedure that is widely used for plant extract compounds, particularly flavors and flavonoids. In spray chilling, the dispersion of core molecule and wall materials are atomized into cooled air, which initiates the solidification of the wall material around the core molecule (Desai & Jin Park, 2005). In spray cooling, the wall material is usually vegetable oil or its derivatives. In spray chilling, the formulated microparticles are maintained at a low temperature in a set-up, and lipid droplets adhere to already hard lipid particles before solidification. The melting point of the lipid used should be in the range of 32°C−42°C for spray chilling and 45°C−122°C for spray cooling (Risch, 1995).

Further, microcapsules formulated by spray cooling or chilling are water insoluble due to lipid layer coating. These two practices, which vary only in the melting point of the wall material used, are most often applied to encapsulate solid materials (Saifullah et al., 2019). Because one can choose the melting point of wall materials, these encapsulation systems can be utilized for the controlled release of guest molecules. Thus spray cooling and spray chilling cannot be employed for encapsulating water-soluble core materials (Desai & Jin Park, 2005). Oriani et al. (2016) produced oleoresin flavor-loaded microparticles through spray chilling by using saturated fatty acids. The study revealed that highly volatile and pungent compounds can be encapsulated through spray chilling. In another study, crystalline particles were formulated for the encapsulation of different flavor compounds through spray chilling by using erythritol as a carrier material (Sillick & Gregson, 2012).

4.3.4 Fluidized bed coating

Fluidized bed coating is one of the most proficient encapsulation systems and is finding evergrowing applications in food industries. In fluidized bed coating process, a coating is applied onto powder particles in a batch or continuous set-up. The powder particles are suspended at a precise temperature by using air stream and sprayed with an atomized coating material (Nedović, Kalušević, Manojlović, Petrović, & Bugarski, 2013). Aqueous solutions of gums, starch, cellulose, and proteins are employed as coating materials for fluidized bed coating. The fluidized bed coating process comprises three basic steps: (1) fluidization of powder particles to be coated in the coating chamber with the assistance of an air stream, (2) spraying of a coating material through a nozzle onto the particles, and (3) evaporation of the solvent of the coating material by hot air, and consequently, the coating material stick to the particles . The drawbacks of fluidized bed coating are direct exposure to high temperature, which can cause guest molecule degradation, and probable cluster formation of developed particles. The authors, Anwar and Kunz (2011), investigated the effect of fluidized bed coating on the stabilization of fish oil microcapsules with maltodextrin, cyclodextrin, and starch. Fish oil stability and bioactivity improved significantly through encapsulation. Using fluidized bed coating, Oehme, Valotis, Krammer, Zimmermann, and Schreier (2011) developed hydroxypropyl methyl cellulose-coated anthocyanin amidated pectin beads as dietary colonic delivery systems.

4.3.5 Extrusion

Encapsulation of plant-derived bioactive compounds by extrusion is relatively new compared with other encapsulation techniques. In extrusion, droplets are produced by extruding a liquid mixture of core and matrix materials. For the extrusion process, the solution-containing core and matrix materials is loaded into a syringe and passed through a needle into gelling conditions to form a gel (Saifullah et al., 2019). During extrusion, the temperature and pressure are kept at below 118°C and 100 psi, respectively. Furthermore, microcapsules prepared by extrusion have a hard, dense, and glassy structure, which protects them from adverse conditions (Nedović et al., 2013). Based on their mechanism, extrusion methods are categorized as jet cutting, spinning disk atomization, and electrostatic simple dripping extrusion (Đorđević et al., 2015). Among all extrusion methods, jet cutting is the best method for industrial applications. The coextrusion process is employed to formulate spherical microbeads with a hydrophobic guest compound and a hydrophilic or hydrophobic matrix material (Nedovic et al., 2011).

Recently, polyphenol-rich chokeberry extract was encapsulated through electrostatic extrusion by using alginate and inulin. Polyphenol-loaded microcapsules displayed higher functionality, and bioavailability of polyphenols (Ćujić et al., 2016). Encapsulation led to higher temperature stability of the plant extract compounds compared with the free compounds. Furthermore, C-phycocyanin isolated from *Arthrospira platensis* was encapsulated through extrusion by using alginate and calcium chloride. The C-phycocyanin-loaded microcapsules presented higher functionality and thermal stability of C-phycocyanin (Pan-utai & Iamtham, 2019).

Electrospinning is an effective approach for formulating sub-micron or nano-scale polymer fibers. In electrospinning, an appropriate polymer solution is spun by a high potential electric field to obtain fibers or particles. In this process, the polymer solution must be highly soluble and have suitable concentration, dielectric properties, and electrical conductivity (Isik, Altay, & Capanoglu, 2018). Tampau, González-Martinez, and Chiralt (2017) reported that carvacrol can be well encapsulated in maize starch-sodium caseinate matrices by electrospinning. Coextrusion is a process that produces beads with the guest compound being enclosed by a matrix (Waterhouse, Wang, & Sun-Waterhouse, 2014). Chew and Nyam (2016) reported that kenaf seed oil can be encapsulated using coextrusion, and encapsulation is an efficient, stable, and reproducible process. In another study, antioxidant-fortified canola oil was encapsulated through coextrusion by using alginate as the encapsulant. Coextrusion significantly changed oil bead characteristics, improved canola oil stability, and maintained the levels of polyphenols (Wang, Waterhouse, & Sun-Waterhouse, 2013).

4.3.6 Emulsion

Emulsion is a standard encapsulation system and is widely used as a delivery system for diverse plant extract compounds because of its better encapsulation efficiency and controlled release properties (Lu, Kelly, & Miao, 2016). Basically, an emulsion system comprises of two immiscible liquids, with one liquid being dispersed as small spherical droplets in the other (McClements, 2015). Moreover, based on the relative spatial distribution of water and oil phases, emulsions can be categorized as follows: water/oil (W/O) emulsions, oil/water (O/W) emulsions, and an alternative to these two emulsions, that is, a water/oil/water (W/O/W) double emulsion (Đorđević et al., 2015). Several emulsion systems with a desired structure and features have recently been established to ensure encapsulation and delivery of numerous types of plant extracts with significant health benefits.

Furthermore, the procedures for emulsion development are diverse, and few of them are injection and gelation of a particular biopolymer dispersion; phase separation and gelation of particular biopolymer dispersion; aggregative separation and gelation of a mixed biopolymer solution (Đorđević et al., 2015). After the formation of an emulsion, a gelling agent can be added to obtain microbeads. Moreover, in emulsions, stabilizers may develop films and offer a barrier to release of core molecule at the internal interface and performance as a steric stabilizer on the external aqueous phase (Zuidam & Heinrich, 2010). Further, an emulsion can be dried by spray or freeze drying to obtain a powder. Finally, the resultant powder form of emulsions have been used as encapsulates in the preparation of diverse functional foods.

Recently, emulsions have been used as a delivery vehicle for plant extract compounds. Usually, plant extract compounds have several health benefits. However, the applications of plant extract compounds in industries are limited because of their major drawbacks, including low water solubility and high sensitivity to processing conditions. Ye et al. (2020) developed a tea polyphenol-loaded emulsion using zein as a stabilizer to expand polyphenol stability as well as its bioactivity during storage. Moreover, emulsions developed using both natural and synthetic emulsifiers expand the stability of plant extract compound, especially resveratrol (Sessa, Tsao, Liu, Ferrari, & Donsì, 2011).

4.3.7 Coacervation

Coacervation, a relatively simple technique, is the partition of two liquid phases in a colloidal solution. At its molecular level, one phase contains polymer (coacervate phase) and the other does not have a polymer (equilibrium solution). The coacervation system is categorized as simple and complex depending on the number of polymer types (Dias, Ferreira, & Barreiro, 2015). In single coacervation, inorganic salts or water miscible non-solvents are typically added to the reaction mixture to initiate phase partition (Xiao, Li, & Zhu, 2015). In complex coacervation, oppositely charged polymers are mixed in a solution to develop a coating around the guest molecule, primarily under the effect of pH and temperature adjustments or in the presence of electrolytic elements (Nori et al., 2011). In complex coacervation, different polymers are utilized for encapsulation of guest molecules, and the typical polymeric pairs consist of gelatin and gums or proteins and polysaccharides (Timilsena, Adhikari, Barrow, & Adhikari, 2016). In food industries, complex coacervation is extensively employed for aroma encapsulation; however, it can only encapsulate water-soluble vitamins and phenolic compounds (Comunian et al., 2013).

Complex coacervation is primarily used to generate favorable encapsulation products with a high loading capacity. Moreover, capsules developed through coacervation are heat resistant and have better controlled release qualities under mechanical stress and temperature and pH shifts (Nori et al., 2011). The major limitation of complex coacervation is that it cannot be used for encapsulating hydrophilic core compounds. Also, the encapsulated particles are not fully spherical, and this process is more expensive. However, complex coacervation is useful for polyphenol encapsulation.

The authors, Nori et al. (2011) encapsulated polyphenol-rich propolis extract through complex coacervation by using pectin and soy protein isolates as encapsulants to enhance the antioxidant activity and stability of polyphenols during storage.

4.3.8 Liposomes

Liposomes are spherical and nano and/or micro-sized colloidal vesicles comprising one or more lipid bilayers. They are nontoxic, biodegradable, biocompatible, and non-immunogenic. Liposomes are widely used for encapsulating lipophilic, hydrophilic, and amphiphilic compounds, which makes them attractive carriers for food industries. Moreover, they are a constructive encapsulation system for water-soluble phenolic compounds as they allow them to expand their stability and maintain their biological activities (Akgün et al., 2020). In addition, liposomes offer pH and ionic strength stability to phenolic and flavonoid compounds. Usually, liposomes form instinctively when phospholipid molecules, such as lecithin and cephalin, are dispersed in water. The basic principle for liposome development is the hydrophilic–hydrophobic interaction between water and phospholipids (Fang & Bhandari, 2010). Moreover, liposomes can entrap hydrophilic compounds in aqueous compartments, hydrophobic compounds within lipid bilayers, and amphiphilic compounds at the aqueous–lipid interface (Hupfeld, Holsaeter, Skar, Frantzen, & Brandl, 2006). Liposomes provide a delivery platform for lipophilic and/or hydrophilic plant extract compounds. However, water soluble liposomal formulations have low kinetic and thermal stability.

Liposomes are yet widely used in food applications; they can be used to deliver functional ingredients or compounds that offer several health benefits to foods. Different practices have been used to formulate liposomes. The major practices are the solvent injection procedure, bubble method, thin-film hydration procedure, and heating-based procedure (Tarone et al., 2020). In recent times, some novel practices have been developed for liposome formation, such as membrane contactor-based process, pro-liposome process, and freeze drying of double emulsion procedure (Emami, Azadmard-Damirchi, Peighambardoust, Valizadeh, & Hesari, 2016).

Liposome encapsulation has recently triggered significant interest in food applications. Moreover, numerous studies have been performed to formulate liposomes as a delivery system for different plant extract compounds. Liposomes stabilize the encapsulated guest compounds against environmental variations during processing and thereafter. Plant extract compounds including polyphenols and flavonoids encapsulated in liposomes can escape digestion in the stomach and shows considerable levels of absorption in the gastrointestinal tract, leading to an increase in bioavailability (Fang & Bhandari, 2010). Gibis, Vogt, and Weiss (2012) formulated soy lecithin liposomes encapsulating polyphenol-rich grape seed extract through high-pressure homogenization. Encapsulation of grape seed polyphenols significantly enhanced their shelf life, and thermal and oxidative stability. Further, Rashidinejad, Birch, Sun-Waterhouse, and Everett (2014) described that liposome formation between green tea catechin and soy lecithin can expand the antioxidant activity of catechins.

However, liposomes are inadequately applied in food industries because of their instability in biological fluids, low storage stability, and poor reproducibility. For liposome formation, formulations need to be maintained in fairly dilute water dispersions, and this may be a main limitation for the large-scale production, and distribution of encapsulated plant extract compounds (Đorđević et al., 2015). To enhance liposome functions, Lu, Li, and Jiang (2011) used the thin-film ultrasonic dispersion method to encapsulate tea polyphenols by using nanoliposomes and observed an increase in tea polyphenol stability and bioavailability. Furthermore, Silva-Weiss et al. (2018) encapsulated quercetin in dipalmitoyl lecithin-based liposomes to maintain and regulate their release in the edible film, thereby improving its bioactivity and expanding food shelf life.

4.3.9 Molecular inclusion

Inclusion complexes are biopolymer-based encapsulation systems that can offer a safe and secure environment for different plant extract compounds. At its molecular level, inclusion complexation involves encapsulation of a core compound into a cavity- or helix-bearing substrate (host material), which was achieved through hydrogen bonding, van der Waals forces, and electrostatic interactions between core and carrier materials (Reddy et al., 2020). Inclusion complexes can be made with starch and its derivatives, including amylose, cyclodextrins (α-, β-, and γ-), chitosan, and β-glucan molecules, which may offer secure and maintain the biological properties of plant extract compounds from hydration, oxidation, and thermal processes.

Cyclodextrins are cyclic oligosaccharides comprising α-D-glucopyranose units joined by α-1,4-glycosidic bonds, which are generated from starch by enzymatic hydrolysis (Periasamy, Nayaki, Sivakumar, & Ramasamy, 2020). At its molecular level, a cyclodextrin molecule consist of a hydrophilic outer surface with several OH-groups, and a hydrophobic central cavity. This unique feature allows cyclodextrin to turn as a matrix or carrier that may formulate inclusion complexes with diverse hydrophobic compounds including flavors, fatty acids, and polyphenols through hydrogen bonding and van der Waals interactions (Numata & Shinkai, 2011). For inclusion complexation, three main forms of cyclodextrins are used, namely α-, β-, and γ-cyclodextrins, which can be made up of six, seven, and eight glucopyranose units, respectively. Among these, β-cyclodextrin is the most commonly used in food and pharmaceutical applications because of its suitable cavity size, accessibility, non-toxicity, and biocompatibility (Reddy et al., 2020). Moreover, β-cyclodextrin consists of a truncated cone-shaped structure with a flexible hydrophobic tridimensional cavity, which permits the development of non-covalent inclusion complexes with diverse guest molecules (Fernandes et al., 2018).

Inclusion complexes of host and guest molecules are formed through co-precipitation, and these inclusion complexes can be dried using spray- or freeze-drying techniques. By forming inclusion complexes with diverse plant extract compounds, cyclodextrins may expand the physical and bio-functional characteristics of plant extract compounds. Also, inclusion complexation increases the stability, aqueous solubility, and biological properties of core compounds against hydration, oxidation, and thermal processes (Ho, Thoo, Young, & Siow, 2017). Several studies have recently been conducted to enhance the water solubility, thermal and chemical stability of plant extract compounds through inclusion complexation with cyclodextrins. Kong, Su, Zhang, Qin, and Zhang (2019) prepared inclusion complexes of grape seed extract with β-cyclodextrin to improve aqueous solubility and reduce sensitivity to extreme environment conditions. Recently, Reddy et al. (2020) described that molecular inclusion of catechin-rich green tea extract by using β-cyclodextrin can expand the thermal stability and antioxidant activity of catechins. Moreover, inclusion complexation can overcome the adverse qualities of polyphenols and protect their antioxidative properties.

4.4 Conclusions

At present, the potential of different plant extracts as the resource of several chemical compounds with crucial biological activities is very well known. Plant extract compounds might be used in distinct areas, including food industries. However, commercial formulations of plant extract compounds are limited owing to their instability, easy degradability, unpleasant taste, and high oxidation sensitivity. This chapter demonstrates an overview of the recent accomplishments in encapsulation of plant extract compounds.

Through encapsulation, plant extract compounds can be incorporated without dropping their functional and quality characteristics. Encapsulation of these compounds also increases their chemical stability, aqueous solubility, biological activities, and shelf life of functional foods. Furthermore, encapsulation delivers a broad range of solutions in this respect—enhancement of sensory attributes, nutrient value, textural properties, and/or health aspects of functional foods.

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