Fortification of Bioactive Components for the Development of Functional Foods

22

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Abstract

One of the most critical uses in the food business is the encapsulation of food components. Bioactive components are being used in food applications due to growing consumer interest in natural ingredients. Encapsulation is a promising method for improving the stability of bioactive components while allowing for regulated release. This chapter presents an overview of various encapsulation procedures, viz. spray drying, freeze-drying, extrusion, emulsification, coacervation, cocrystallisation, supercritical fluid method, and different encapsulated bioactive compounds, which have been used to fortify food components and deliver them into various functional foods.

Keywords

Encapsulation · Spray drying · Freeze-drying · Extrusion · Emulsification · Coacervation · Cocrystallisation

22.1 Introduction

Nutraceuticals, a term devised by Stephan DE Felice in 1979 to express their presence in the human diet and biological activity, are also termed bioactive components. In addition to the fundamental nutritional value, bioactive components found in food as natural ingredients give health beneficial properties. "Bioactive compounds" are extra nutritional components that characteristically occur in minor quantities in foods. They are being thoroughly examined to see how they influence the public's health. They contain compounds present in small amounts of vegetation

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and particular foods like fruits, vegetables, nuts, oils, and grains. The overview of some of the essential potential health benefits of bioactive compounds is as follows:

- Improved brain health and reduced oxidative stress
- Lowering of blood pressure and cardiovascular disease
- Anticancer
- Antidiabetic
- Better intestinal health
- A better lipid profile

22.2 Sources of Natural Bioactive Compounds

Tropical plants, aquatic cyanobacteria, microalgae, and filamentous fungi have bioactive compounds explored in their biological matrices. As a result, current studies into these compounds and their sources are becoming more common.

22.2.1 Plant Tissues

Plants manufacture two types of bioactive, viz. primary and secondary metabolites (Wu and Chappell 2008). Primary metabolites encompass sugars, amino acids, fatty acids, and nucleic acids, and all plants are used for growth and development, such as growth factors and cell wall components. Secondary metabolites play a set of functions within the plant's existence cycle and modulate plant–environment interactions like plant–microbe, plant–insect, and plant–plant interactions, and pollinating and attracting pollinators (Balandrin et al. 1985). As a result, these secondary metabolites are helpful for a wide range of actions, and scientists investigating their bioactivity for practical applications are of particular interest. The plant's physiology and biological process stage impact the natural synthesis of these metabolites (Table 22.1).

Plant secondary metabolites can be categorised into five groups depending on their metabolic origin: Polyketides include isoprenoids, alkaloids, phenylpropanoids, and flavonoids (Oksman-Caldentey and Inzé 2004). Plant secondary metabolites can be categorised into five groups depending on their metabolic origin: Polyketides include isoprenoids, alkaloids, phenylpropanoids, and flavonoids (Oksman-Caldentey and Inzé 2004). These compounds are only produced in specific cell types and at specified stages of growth or during particular periods, making their isolation and purification extremely tough (Verpoorte et al. 2002). Carotenoids, terpenoids, alkaloids, phenylpropanoids, and some specialised compounds such as corilagin, ellagic acid, vinblastine, and vincristine are commercially used secondary plant metabolites (Sőzke et al. 2004; Nobili et al. 2009; Yang et al. 2010) and are used in the production of pharmaceuticals and also can be employed as a food additive to improve food functioning (Shahidi 2009; Ayala-Zavala et al. 2010).

Table 22.1 List of bioactive components from plant sources

Plant source	Bioactive components	Health benefits	References
Buckwheat	Bioactive peptides (DVWY, FDART, FQ, VAE, VVG, and WTFR)	Lowering of blood pressure	Koyama et al. (2013)
Chia seeds	Bioactive peptides (ACE inhibitory)	Lowering of blood pressure	Campos et al. (2013)
Maize seed	Anthocyanins (cyanidin–glucoside, cyanidin–malonylglucoside, pelargonidin–malonylglucoside, cyanidin–dimalonylglucoside)	Prevention of cardiovascular diseases	Toufektsian et al. (2008)
Olive oil	Polyphenols (hydroxytyrosol)	Prevention of cardiovascular diseases	Tejada et al. (2017)
Eggplant	Eggplant peel extract	Poisonous effect on cancer cells	Afshari et al. (2017)
Eggplant	Glycoalkaloids (solasodine and solamargine)	Anticancer activity	Shen et al. (2017)
Soy	Isoflavone genistein	Anticancer activity	Montales et al. (2012)
Maclura Pomifera	Pomiferin (inhibitor of glioma)	Therapeutic agent/anticancer activity	Zhao et al. (2013)
Blueberries	Polyphenolic acids (pterostilbene)	Anticancer activity	Mak et al. (2013)
Quinoa	Chenopodium peptides	Antidiabetic effects	Vilcacundo et al. (2018)

Natural bioactive compounds found in plant tissues are essential because they have an extensive range of biological activities and bioactive properties. They must play a vital part in the evolution of new commodities (Wu and Chappell 2008). Natural bioactive has been the source of 60–70% of healthy development for cancer and infectious diseases over the last two decades (Newman and Cragg 2007). It has been reported that more than two-thirds of the world's population still gets primary medicinal care from medicinal plants (McChesney et al. 2007). Additionally, the human population has carefully investigated these compounds and proved to have beneficial health effects on humans; furthermore, research data are required to ensure their safety and efficacy.

22.2.2 Microorganisms

Microorganisms are vital because they employ their biological system to manufacture essential biomolecules (Demain 2000; Donnez et al. 2009). An average of almost 23,000 natural bioactives of microbial origin have been discovered, most of

Table 22.2 List of bioactive components from microorganisms

Microorganisms	Health benefits	References
Cyanobacteria		
Dolastatin 10	Antitumor	
Dolastatin 15	Antitumor	
Curacin A	Antimicrotubule	
Toyocamycin	Antifungal	Burja et al. (2001)
Actinomycetes		
Resistoflavine	Anticancerous	Gorajana et al. (2007)
Marinomycin A	Antibiotic	Kwon et al. (2006)
Daryamide C	Antitumor	Asolkar et al. (2006)
Violacein	Antiprotozoal	Matz et al. (2008)
Bacteria		
Macrolactin S	Antibacterial	Lu et al. (2010)
Pyrones I and II	Antibacterial	Maya et al. (2003)
MC21-B	Antibacterial	Isnansetyo and Kamei (2009)
Fungi		
Meleagrin	Antitumor	Du et al. (2010)
Oxaline	Antitumor	Koizumi et al. (2004)
Alternaramide	Antibacterial	Kim et al. (2009)

which are produced from a limited number of microorganisms (Olano et al. 2008). Fungal organisms have been found in practically every living and non-living habitat on the planet, including deep rock deposits, deserts, and aquatic environments (Strobel 2003). Plants and prokaryotes of fungal origin generate bioactive compounds beneficial to the environment (Table 22.2). These compounds can perform various functions, including preventing photooxidation, protecting against environmental stress, and being used as cofactors in enzymatic reactions (Mapari et al. 2005). Fungal species such as *Penicillium*, *Aspergillus*, and *Streptomyces* produce bioactive antibiotics, enzymes, and organic acids, having beneficial effects (Liu et al. 2004; Silveira et al. 2008).

Natural bioactive substances manufactured by microorganisms can be employed as nutritional supplements, flavour-inducing agents, texturisers, preservatives, emulsifiers, acidulants, surfactants, or thickeners in food. Bioactive compounds extracted from bacteria include isoprenoids such as carotenoids (beta-carotene and lycopene), and phenylpropanoids such as stilbene derivatives (resveratrol and others) have beneficial properties (Chang and Keasling 2006; Klein-Marcuschamer et al. 2007; Ajikumar et al. 2008; Donnez et al. 2009). However, only 1% of bacteria are cultivated in vitro, implying that microorganisms have diverse biodiversity, and many natural bioactivities are still being investigated. The main reason behind using microorganisms (rather than microbes) to generate compounds from plants and animals is the high efficiency with which high yields can be developed and the possibility of environmental and genetic modification (Demain 2000). Additionally, bacteria can create several vital compounds in small quantities for their advantage

(Demain 2000). Nevertheless, because the number of bioactive compounds produced is minimal, their application in this field is limited.

22.2.3 Algae and Microalgae

Algae can be found in various surroundings, including the ocean, freshwater, and deserts (Guschina and Harwood 2006). Over 30,000 genera of microalgae are present globally, and over 15,000 novel compounds have been chemically isolated from them (Metting John 1986; Cardozo et al. 2007; Rodríguez-Meizoso et al. 2010).

Researchers have revealed that these compounds exhibit a wide range of biological effects, and their importance as a source of novel compounds is proliferating (Wijesekara et al. 2010).

Many bioactive compounds are present in algae possessing antioxidant, antibacterial, and antiviral properties (Onofrejová et al. 2010; Plaza et al. 2010; Rodríguez-Meizoso et al. 2010). These organisms adapt rapidly and successfully since they live in a hostile atmosphere, producing many physiologically active secondary metabolites that boost natural defence mechanisms (Rodríguez-Meizoso et al. 2010). These defence mechanisms can result in mutations in molecules hailing from different metabolic pathways (Table 22.3).

Carotenoids, polyphenols, and other antioxidant pigments, as well as polyphenols, notably quercetin, catechin, and tiliroside, acid derivatives, and dipeptides, are produced by microalgae (Lam 2007). Algae have not only bioactive compounds but also possess extraordinary diversity and ability to harvest and grow under a variety of conditions making them significant, thereby resulting in the economic gain and production of a variety of bioactive compounds that can be used in the pharmaceutical and food industries as part of new stimulants or supplements (El Gamal 2010).

Although natural bioactive substances can be derived from various sources, one of the inhibiting variables in their synthesis is the low concentration they can generate. Many scientists worldwide are presently exploring novel techniques to optimise the recovery and synthesis of natural bioactive compounds.

Table 22.3 List of bioactive components from an algal source

Algae	Health benefit	References
Norharman	Enzyme inhibitor	Volk (2008)
Calothrixin	Antimalarial and anticancerous	Rickards et al. (1999)
Eicosapentanoic acid (EPA)	Prevents cardiovascular diseases, anti-inflammatory	Singh et al. (2005)

22.3 Fortification of Bioactive Components by Encapsulation Techniques

There has been a significant emphasis on human well-being in recent years, mainly through nutritional approaches. The nutraceuticals and functional foods industries have witnessed many innovations to accomplish customers' requirements. People are looking for novel and safer dietary elements that will supply nutrition and boost their health and well-being. As a result, consumers' attention has been drawn to food bioactive molecules, nutraceuticals, and functional foods. Many diets contain bioactive molecules such as vitamins, pigments, enzymes, flavours, and vital fatty acids. However, these bioactive molecules are susceptible to destruction due to heat, light, oxygen, and other stressors (Assadpour and Jafari 2019).

Because many bioactive compounds are poorly solvable, micro/nanoencapsulation simplifies the transfer of poorly soluble bioactive molecules into functional food components (Bazana et al. 2019). It promotes bioactivity and the physical stability of bioactive in produced foods and during processing. Bioactive compounds are better absorbed in the gastrointestinal tract when encapsulated (Zanetti et al. 2018). Encapsulation is often used to prevent bioactive compounds from reacting with other degrading elements like oxygen and light (Suganya and Anuradha 2017; Nedovic et al. 2011).

On a nanoscale, micrometre, and millimetre scale, encapsulation is the process of embedding one material into another and preparing particles (Burgain et al. 2011). Encapsulation is being used in several industries, and its rapid growth has influenced many sections of the food business, including processing, packaging, and storage. There are multiple methodologies for encapsulating bioactive components, but none of them can be referred to as a universal medium. Encapsulation enhances the transfer of bioactive substances and allows for a controlled drug release over time. This methodology helps to ensure the compound's security, efficacy, and stability (Zanetti et al. 2018). The product size in microencapsulation ranges from 1 to 1000 μm. However, the size and shape of the substance in nanoencapsulation should be smaller than 1 μm (1000 nm), as this encourages more accessible active sites on the surface of these delivery systems, facilitating absorption in the digestive system (Suganya and Anuradha 2017). The encapsulation efficiency is determined by the encapsulation technology used, the wall material used, and the process variables used (Kavitakea et al. 2018).

The various factors affecting the microencapsulation efficiency include the following:

1. Capsule characteristics concerning the environment
2. Polymer concentration and bead diameter
3. Capsule material, coatings, and processes
4. Initial concentration of microbial cell
5. Environmental conditions
6. Modification of capsule material

7. Effect of the bacterial cell on capsule
8. Condition of processing factors

22.4 Encapsulation Techniques

22.4.1 Spray Drying

For many years, spray drying has been employed to produce powders. Spray drying converts a liquid feed into a dried particulate form by spraying it into a hot air drying medium. It generates fine particles in a shorter timeframe and at a lesser cost per operation unit (Masters 1991). It is often commonly used in industrial processes due to its continuous production of powders with a low water activity (Anandharamakrishnan et al. 2008; Kuriakose and Anandharamakrishnan 2010). Moreover, this technology over decades has been frequently used for encapsulation in the food industry. Spray drying has also been used to encapsulate a wide variety of food ingredients, including flavours, vitamins, minerals, colours, fats, and oils, to protect them from the harsh conditions of the environment and thereby preserve the food (Pillai et al. 2012). As a result, it fits the definition of being a good microencapsulation technique (Table 22.4).

Spray drying of nanoparticles has been proposed as a promising method for producing macroscopic compact structures and submicron spherical powders having nanometre-scale properties (Okuyama and Lenggoro 2003).

It was reported by Jafari et al. (2007, 2008) that Hi-Cap modified starch was found superior to whey protein isolates due to having less interface oil in the encapsulated powders. The nanosize of the emulsion droplets was reported to be 200–800 nm, but during spray drying, they were altered to a micron size of above 20 μm. To encapsulate catechin in a carbohydrate matrix, Ferreira et al. (2007) employed homogenisation proceeded by spray drying at a temperature of 150–190 °C and manufactured spherical-shaped particles with smooth surfaces having a diameter in the range of 80 nm. Encapsulating catechins also lowered oxidation while increasing bioavailability.

De Paz et al. (2012) reported nanosuspensions synthesising by encapsulating beta-carotene with modified octenyl succinate starch and spray drying them. The nanosuspensions were synthesised under different experimental operating conditions with high antioxidant activity and enhanced encapsulation effectiveness of 65–90% and a particulate size ranging from 300 to 600 nm. However, after spray drying, the particles collected were around 12 μm in diameter.

In the dairy industry, the utilisation of nonfat milk, whey protein, and casein powders has been widely used to enhance milk and milk-related products (Schuck et al. 2016). Spray drying is generally accomplished by atomising the feed solution and injecting and circulating hot air into a drying compartment with a predefined inflow temperature. The input solvent is then evaporated at an exact moment by the hot air. The hot air then evaporates the input solvent in an instant. A cyclone collects

Table 22.4 Encapsulation techniques of various bioactive compounds

Nanoencapsulation technique used	Raw material used	Bioactive compound	Important inference	Reference
Spray drying	Wall material used: carbohydrate matrix and maltodextrin	Catechin (H)	Increasing the stability of the product, protecting it from oxidation, and incorporating it into beverages	Ferreira et al. (2007)
Coacervation	Wall material used: tannins, gelatine, and maltodextrin	Capsaicin (L)	Biocompatibility and biodegradability are provided by masking the punitive odour	
	The emulsifier used: Tween-60			
Freeze-drying	Wall material used: polycaprolactone, β-cyclodextrin	Fish oil (L)	Defending against oxidation and concealing the odour	Choi et al. (2010)
	Emulsifier used: Pluronic F68			
Emulsification	Wall material used: maltodextrin; emulsifier used: modified starch (Hi-Cap 100)	D-limonene (L)	Preventing recoalescence of the droplets	Jafari et al. (2007)
Supercritical fluid technique	Wall material used: hydroxypropyl methylcellulose phthalate	Lutein (L)	Bioactivity, food industry promotion, and protection from thermal and light degradation	Heyang et al. (2009)

the produced particles (the exit temperature is specified to be lower than the entrance temperature in this section) (Deshmukh et al. 2016).

Spray drying nanocapsules is a great idea to maintain their shelf stability. It continuously produces spherical particles that protect the core material enclosed in them. Drying nanoemulsions and nanosuspensions results in the formation of micron-sized particles. The core material inside the micron-sized particle matrix had been in the nanosize range (nanosuspension and nanoemulsion), which Jafari et al. (2007) demonstrated as nanoparticle encapsulation. In particular, spray drying nanoencapsulation is interdependent on other nanoencapsulation techniques (such as emulsification) before spray drying. As a result, conventional spray drying may not be considered an independent nanoencapsulation method. On the other end, spray drying permits particle size and morphology to be controlled by modifying process parameters and formulations (Anandharamakrishnan et al. 2008). As a result, spray drying must be adjusted appropriately to preserve the nanoscale size of nanoemulsions and suspensions. The schematic presentation of the spray drying procedure is shown in Fig. 22.1.

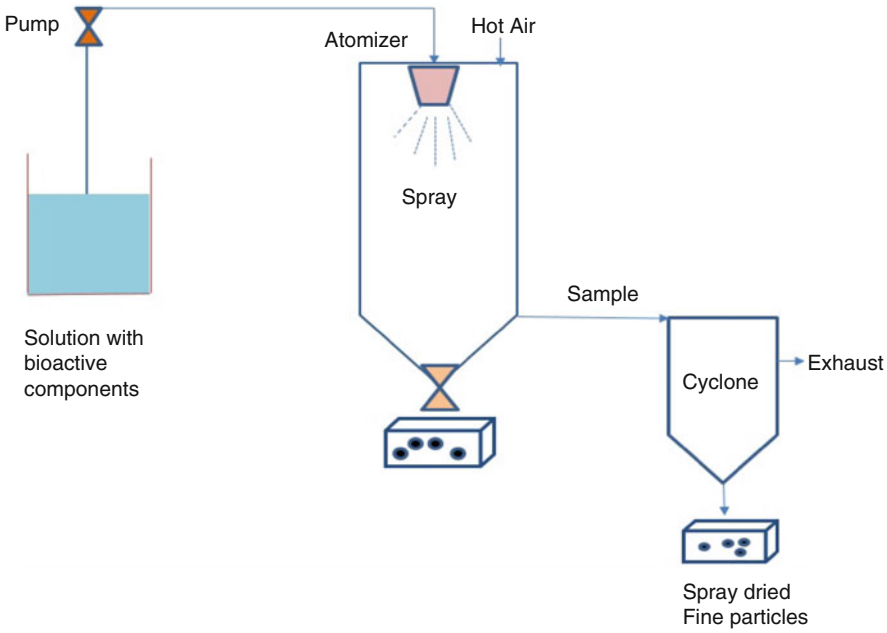

Fig. 22.1 Spray drying procedure

22.4.2 Coacervation

Coacervation is the method for separating a single or a mixture of polyelectrolytes from a solution and distributing the newly formed coacervate phase around the active constituent. By crosslinking hydrocolloid shells with a suitable chemical or enzymatic crosslinker such as glutaraldehyde or transglutaminase, the durability of coacervate can be increased (Zuidam and Shimoni 2010). Coacervation can be categorised into simple coacervation (using only one kind of polymer) and complex coacervation (using multiple polymer types). The several factors that regulate the strength of interactions between the biopolymers and the nature of the complex formed include the type of biopolymer, pH, ionic strength, concentration, and biopolymer ratio (Tolstoguzov 2003; De Kruif et al. 2004; Turgeon et al. 2007). Hydrophobic contacts and hydrogen bonding can play an essential role in forming complexes, despite ionic interactions between biopolymers with opposing charges. According to Gouin (2004), coacervation is a unique and effective encapsulation method because of the high payloads (up to 99%) and controlled release options based on mechanical stress, temperature, or sustained release. To encapsulate capsaicin, Wang et al. (2008) accomplished a simple coacervation technique by using gelatine, crosslinked with glutaraldehyde, and dehydrated in a vacuum oven. The nanocapsules produced were 100 nm in diameter. Due to the crosslinking of gelatine over the surface of capsaicin, the melting and thermal temperature of the nanocapsules were improved. Xing et al. (2004) performed a complex coacervation

methodology to encapsulate capsaicin in gelatine and acacia. The nanocapsules were manufactured by freezing encapsulated capsaicin after treating it with hydrolysable tannins and crosslinking it with glutaraldehyde. Nanocapsules have spherical shapes with a mean diameter of 300–600 nm. The overall encapsulation efficiency in this analysis was 81%, with good dispersion characteristics. Due to the synergistic effects of hydrogen bonding and hydrophobic effects, adding hydrolysable tannins to the mixture considerably impacted the nanocapsules' shape and particle size distribution, used a similar complex coacervation technique with a vacuum oven to encapsulate capsaicin. Having stronger shearing force (15,000 rpm agitation rate), reduced gelatine viscosity (15–20 cPs), suitable crosslinking length (40–80 min), use of tannin, and other required experimental parameters all improved nanocapsule production as investigated by researchers. The nanocapsules produced exhibit specific properties like having spherical morphology, an average diameter of about 100 nm, a higher melting point (75–85 °C), and higher breakdown properties. Gan and Wang (2007) encapsulate bovine serum albumin (BSA) in chitosan by using polyanion tripolyphosphate (TPP) as crosslinking agent. BSA-loaded chitosan-TPP nanoparticles successfully synthesised under varying conditions had diameters ranging from 200 to 580 nm. A quantitative sequential time frame transmission electronic microscope (TEM) imaging displayed a swelling and particle breakdown process, revealing the morphological alteration of BSA-loaded particles. According to their conclusions, the polyionic coacervation process may be controlled to modify protein encapsulation efficiency and release profile.

The coacervation method produced 100–600 nm nanocapsules. This method used gelatine, acacia gum, and chitosan as wall components. The morphology (outstanding dispersion and shape) and particle distribution of nanocapsules were also impacted by tannin treatment. After crosslinking with glutaraldehyde for a specific period, the nanoencapsulation's melting point and thermal stability were increased. The biggest challenge with this procedure is actively promoting the coacervated foodstuffs due to the usage of glutaraldehyde for crosslinking, which must be used cautiously according to the country's legislation. Despite this, many crosslinking enzymes are currently being created (Gouin 2004).

22.4.3 Freeze-Drying

Freeze-drying, also described as lyophilisation, is a technique for dehydrating practically all heat-sensitive materials and aromas (Anandharamakrishnan et al. 2010). *Freeze-drying* is a multistage procedure encompassing freezing, sublimation (primary drying), desorption (secondary drying), and, subsequently, storage. Freeze-drying produces commodities that are greater in durability, easier to reassemble, and have a longer shelf life. According to Singh and Heldman 2009; freeze-drying's main disadvantages were its high-energy consumption, long processing time (over 20 h), and open porous structure. On the other hand, freeze-drying is often used to separate nanoparticles manufactured by other nanoencapsulation methods (i.e. removing water from the compounds). During the freeze-drying process,

pores develop due to the ice sublimation process. As a result, this technology is not strictly encapsulated because active food elements are exposed to the atmosphere due to porosity on the particle surface. As a result, any release mechanism, such as diffusion or erosion, is challenging to develop. The freeze-drying technology is now the most widely used method for evaporating water from nanocapsules without causing structural or form changes.

As a substitute for spray drying, freeze-drying of heat-sensitive bacteria combined with matrix molecules has been proposed (Augustin and Hemar 2009). Choi et al. (2010) utilised cyclodextrin (-CD) and PCL (Food and Drug Administration (FDA)-approved edible drug delivery material) to encapsulate fish oil using a self-aggregation approach and an emulsion diffusion method with freeze-drying. With a mean particle size of 250–700 nm, PCL/fish oil (99%) has higher fish oil loading and encapsulation efficiency and much less fish oil leakage than -CD fish oil (84–87%). Bejrapha et al. (2010) assessed the stability of fish oil-filled nanocapsules encapsulated in PCL when they used vacuum freeze-drying (vacuum-pressured freezing and drying) vs. standard freeze-drying (atmospheric pressurised freezing and drying). In their study, the particle size of fish oil nanocapsules was revealed to be below 360 nm, and they were discovered to be aggregated. Vacuum freeze-drying demonstrated a higher encapsulation performance than traditional freeze-drying except at a freezing temperature of −30 °C. Furthermore, the researchers noted that the vacuum freezing approach might damage the PCL membrane due to poor encapsulation performance and particle aggregation.

Ionic gelation, sonication, and freeze-drying were adopted by Dube et al. (2010) to encapsulate (+) catechin and (−) epigallocatechin gallate (EGCG) in chitosan-tripolyphosphate. Nanoencapsulation's potential to inhibit catechin and EGCG degradation was compared to the addition of reducing agents, including ascorbic acid, dithiothreitol, and (tris 2-carboxyethyl) phosphine (TCEP). Nanocapsules have an average particle size of fewer than 200 nm. The reducing agents TCEP and ascorbic acid conferred lesser protection than catechin and EGCG nanoencapsulation. Surassamo et al. (2010) encapsulated capsicum oleoresin in PCL through using the emulsion diffusion method (the method involves forming an emulsion between a water-miscible solvent containing drug and the aqueous polymer phase; adding water to the system causes the solvent to diffuse to the external degree, leading to the formation of nanospheres). The process conditions were optimised by varying the concentration of the surfactant, Pluronic F68 (PF68). Nanoemulsions with a diameter of 320–460 nm were generated—the size of the nanocapsule particles reduced as the emulsifier concentration was raised. As the surfactant concentration was increased, the particle size contracted. Using an emulsion–diffusion method followed by freeze-drying, Nakagawa et al. (2011) analysed the dispersibility of capsicum oleoresin encapsulated in PCL and stabilised with gelatine. The nanocapsules have a diameter of fewer than 200 nm on average. The dried bulk sample also revealed that the created freeze-dried capsules had variable dispersion characteristics in different regions. The diversity was influenced by the cooling programme utilised during the processing. They indicated that

forming a gel network in nanocapsule gelatine will assist in the development of better nanocapsule dispersion characteristics after drying.

To make capsicum oleoresin-loaded nanocapsules with PCL, Bejrapha et al. (2011) applied a modified emulsion–diffusion process combined with freeze-drying. The consequences of freezing temperatures on the characteristics of capsicum oleoresin-loaded nanocapsules were studied at −40, −20, and −15 °C. The effects of active ingredients such as gelatine and κ-Carrageenan on the stability of capsicum-loaded nanocapsules during freeze-thawing and freeze-drying methodologies were evaluated. According to their observations, the size of nanocapsules after freeze-thawing and freeze-drying was significantly influenced by a relatively high temperature (−15 °C). Abdelwahed et al. (2006) investigated the freeze-drying of PCL nanocapsules encapsulating MIGLYOL 829 oil produced by emulsion–diffusion and stabilised by polyvinyl alcohol. During the freeze-thawing study, PVA and PCL concentrations, cooling rate, cryoprotectant concentrations (sucrose and polyvinyl pyrrolidone), type of encapsulated oil, and nanocapsule purity were all studied. The outcome of annealing on nanocapsule stability and sublimation rate has also been explored. They demonstrated that if the PVA stabiliser concentration is high enough (5%), PCL nanocapsules can be freeze-dried without the need for a cryoprotectant. The size and rehydration of freeze-dried nanocapsules were almost unaffected by the kind of cryoprotectant used, and the annealing method expedited sublimation while keeping the nanocapsule size constant. Tiyaboonchai et al. (2007) encapsulated curcuminoids into solid lipid nanoparticles using the microemulsion method and freeze-drying. Under optimum process conditions, lyophilised curcuminoid-loaded nanoparticles revealed spherical particles with a mean particle size of 450 nm and incorporation efficacy of up to 70%. According to the findings, the proportion of components such as fat and emulsifier substantially impacted the curcuminoid loading capacity and size distribution. Curcuminoids were formed slowly (up to 12 h) and retained their physical and chemical stability over a 6-month storage period, according to in vitro release experiments.

Zhang et al. (2009) exploited the freeze-drying method to encapsulate trehalose in a thermally responsive pluronic nanocapsule. The nanocapsule may physically contain trehalose for cellular ingestion at 37 °C with only minimal release in hours, and its cytotoxicity is low. To encapsulate tocopherol in zein and zein/chitosan complexes, used a freeze-drying approach. The particle size of the compound ranged from 200 to 800 nm, and the efficacy of encapsulation ranged from 77% to 87%. The kinetic release profile of tocopherol showed a burst effect followed by progressive release. The zein/chitosan complex produced more tocopherol release against acute gastroenteritis than zein alone due to the chitosan coatings. To synthesise standard liposomes and polyethylene glycol (PEG)-coated vitamin E lyophilised proliposomes, Zhao et al. (2011) used thin-film ultrasonic dispersion and lyophilisation (PLP). Proliposomes are coated with PEG and lyophilised with a mean diameter of 164 nm and encapsulation efficiency of 84%. Vitamin E contained in PLP presented more excellent stability than standard liposomes, with a retention percentage of 90% at 4 °C after 15 days of storage.

For nanocapsule stabilisation, freeze-drying proves to be an effective drying process. Even after drying, it retained particle sizes in the nanometric range (below 400 nm and a few near 800 nm), improving core component stability against degradation and reaching a 70% encapsulation efficiency. It also appears to be an excellent drying process for heat-sensitive foods and bioactive components. The attributes of the final freeze-dried nanoparticles, on the other hand, are dependent on the use of a suitable high-energy emulsification procedure and other encapsulating techniques for breaking down the droplets into nanoform. Cryoprotectants such as sucrose, trehalose, and mannitol are also necessary to maintain particle size and reduce aggregation during freeze-drying. The size of nanocapsules has been affected by varied freezing temperatures. Polymers such as PCL and chitosan were used as a wall material in the majority of the researches.

22.4.4 Extrusion

Extrusion technologies are affordable and straightforward but take a long time to complete. The process of propelling a solution through nozzles or small apertures in droplet-generating equipment to produce a tiny droplet of an encapsulating substance is known as extrusion—the smaller the inner diameter of the nozzle or opening, the small the capsules. Industry-focused groups typically argue that this approach is only appropriate for laboratory processes and does not allow large-scale production. Extrusion-based upscaling of encapsulating technologies, on the other hand, has made enormous progress. Multiple nozzle systems, spinning disc atomisers, and jet-cutter techniques can all be used (De Vos et al. 1997; Kailasapathy 2002).

In most cases, extrusion technology has the advantage of being an accurate encapsulation method rather than an immobilisation technique. Swelling can be decreased during the encapsulation technique by selecting materials with low or negligible swelling kinetics and an appropriate quantity of cells per millimetre of encapsulating substance (De Vos et al. 1996a, b). When it comes to encapsulating bacteria, extrusion technologies offer a variety of benefits. It is low impact, chemical-free, and can be done in aerobic and anaerobic situations. When anaerobic microbes are used in food items, this is exceptionally advantageous. The modifications required to accomplish this are relatively simple. The extrusion device must be warehoused in a sterile cabinet with oxygen replacing nitrogen. Extrusion technology is used to make flavours, enzymes, and proteins.

22.4.5 Emulsification

Emulsification refers to dispersing one liquid into a second immiscible liquid. The bioactive component can be encapsulated by immersing the core material in the first liquid. In most instances, researchers and industry use electrostatic interactions, hydrophobic interactions, or hydrogen bonding between the bioactive molecule

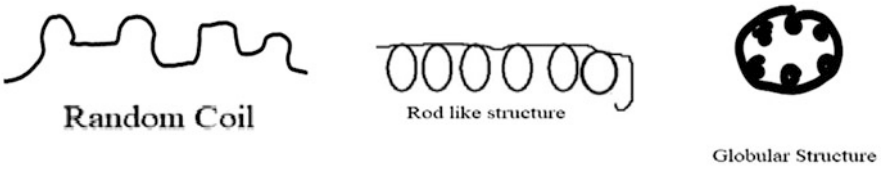

Fig. 22.2 Transition in molecular conformation by emulsification technique

and the encapsulating molecule to encapsulate bioactive components in food-grade (GRAS)-derived molecules. The encapsulating agent is usually a chemical found in food (Augustin and Hemar 2009). Surfactants that assist encapsulation by forming micelles, vesicles, bilayers, and reverse micelles around bioactive substances are also commonly prescribed as a remedy (Augustin and Hemar 2009; McClements et al. 2009a, b). When lipase is secreted, it safeguards the bioactive molecules in the products and allows them to pass through the duodenum. Biopolymers, such as proteins and polysaccharides, can also be used to encapsulate sensitive bioactive compounds by constructing random coil, sheet, or rod-like structures around them (Fig. 22.2). The biopolymer's type and digestibility impact how quickly it is absorbed in the gut (Champagne and Fustier 2007; McClements et al. 2009a, b). The biopolymer used is determined by the product's content. Bulk emulsification techniques are used in some situations to improve packing efficacy. The bioactive compounds are often encased in fat droplets or water–oil–water emulsions (Augustin and Hemar 2009; McClements et al. 2009a, b). Bulk emulsification is more commonly thought of as a technique for finely controlling the release of molecules rather than a natural encapsulating system. A large number of dietary components can be used as emulsion building blocks. The options are vast and have been thoroughly examined (Augustin and Hemar 2009). The use of monoglycerides can briefly explain the emulsification principle. Monoglycerides can self-assemble into a range of forms in water. With minimal and non-laborious modification, micelles, hexagonal, cubic, or even lamellar geometries of glycerides that enclose one or more bioactive chemicals can be developed. It is a simple technology that is already being used to control the release of odours and flavours (Augustin and Hemar 2009).

A modified version of the solvent evaporation process is the emulsification solvent evaporation technique, whose schematic representation is shown in Fig. 22.3.

22.4.6 Co-crystallisation

Co-crystallisation is a technique that requires immersing active composites in a high-carbohydrate solution. Over-saturation causes carbohydrate crystallisation, which begins with a decline in temperature. The compound to be enclosed becomes imprisoned as the crystal form (Champagne and Fustier 2007). Because of its simplicity and improved stability, co-crystallisation is cost-effective and adaptable.

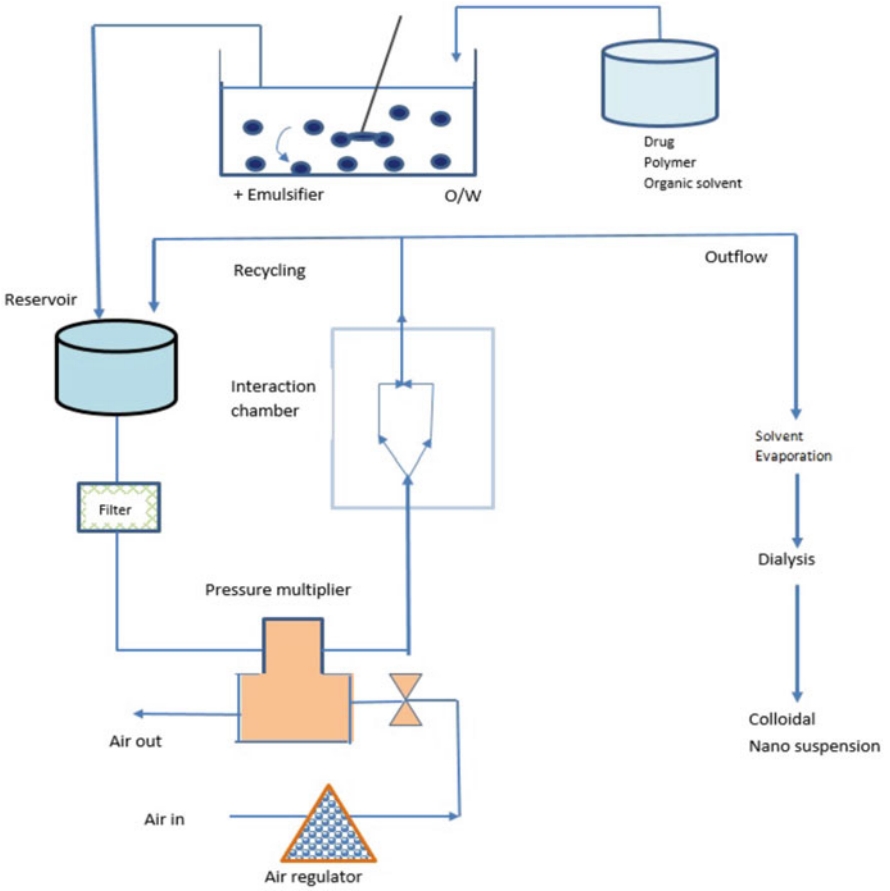

Fig. 22.3 Nanoparticle preparation by emulsification solvent evaporation (Kwon et al. 2006)

The disadvantage of this approach is that it produces low hygroscopic granular products, and the heat-labile core bioactive substance may be degraded (Pegg and Shahidi 2007).

22.4.7 Supercritical Fluid Technique

A supercritical fluid is a liquid or gas used at temperatures and pressures higher than its thermodynamic critical point (Jung and Perrut 2001). Supercritical fluids, intermediate between liquids and gases, have low viscosity, low density, solvating solid power, high diffusivities, and high mass transfer rates above the critical points. Supercritical conditions can be achieved with carbon dioxide, water, propane, nitrogen, and other substances (Gouin 2004). Some of the technologies utilised in supercritical fluid technology include rapid expansion from supercritical solution,

gas antisolvent, supercritical antisolvent precipitation, aerosol solvent extraction, and precipitation with a compressed fluid antisolvent (Kikic et al. 1997).

Supercritical fluids encapsulate thermally sensitive compounds in a process similar to spray drying. In this method, the bioactive component and polymer were dissolved in a supercritical fluid before inflating through a nozzle. During the spraying operation, the supercritical liquid was evaporated, resulting in the precipitation of solute particles (Reis et al. 2006). This approach is widely used due to its low critical temperature and limited use of organic solvent.

Heyang et al. (2009) used supercritical antisolvent precipitation to encapsulate lutein in hydroxypropyl methyl cellulose phthalate (HPMCP) to retain its bioactivity and avoid thermal/light degradation. A variety of parameters, including lutein loading efficiency, particle size, and nanocapsule distribution, influenced the yield.

22.5 Conclusion

Nanoencapsulation techniques have been shown to have a higher possibility of increasing the efficacy of bioactive component delivery in humans. Various nanoencapsulation techniques evolve, each with its advantages and disadvantages. Lowering the risk of specific diseases in a population is predicted to be met by a nano-approach in distributing bioactive food components with documented health benefits.

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