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Encapsulation of Food Components and Bioactive Ingredients and Targeted Release

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The potential utilization of encapsulation techniques in food, pharmaceutical and agricultural products preparation, presents a new alternative for complementary technologies such as targeting delivery vehicles and carriers for active food ingredients. Encapsulation could be accomplished by different techniques like: simple or complex coacervation, emulsification technique, phase separation, spray drying, spray chilling or spray cooling, extrusion coating, freeze drying, fluidized-bed coating, liposomal entrapment, centrifugal suspension separation, co-crystallization and molecular inclusion complexation. Encapsulation is a method by which one bioactive material or mixture of materials is coated by the other material. It is designed for protection, isolation, assists in the storage and controlled release. A timely and targeted release improves the effectiveness of ingredients, broadens the application and ensures optimal dosage, thereby improving cost-effectiveness process for manufacturers. This review highlights recent innovations in encapsulation and controlled release technologies. In addition, design principle of novel peppermint oil delivery systems which displays the new structured biomaterials for capsules fabrication by complex coacervation technique, besides microemulsification method for bioactive material, *Lactobacillus* encapsulation and targeted release studies reported.

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1. INTRODUCTION

Food technology is a new technology by which advanced products and processes in the food industry can be generated by recent concerns. Nanotechnology is defined a system which controls shape and size at nanoscales [1]. A decrease in the size of particle to nanoscales results in a manifold increase in reactivity, while altering the mechanical, electrical, and optical characteristics. Hence, unique and desired physical properties can be obtained by monitoring the morphology, composition, and size of materials [2,3]. Moreover, nanotechnology can enhance the quality of the substantial such as thermal stability, water solubility, and bioavailability of bioactive substances [3-6]. In fact, this technology introduces new chances for revolution in the food industry especially in nutrient encapsulation methods at a remarkable speed. The encapsulation technology has changed the whole food cycle process from production to storage. It has also changed the creation of innovative products and their applications [7-10].

Food-based micro or nano carrier systems are generally based on protein, carbohydrate, or lipids [11-13]. There are numerous kinds of lipid-based microparticulate delivery systems such as microemulsions, microliposomes, solid lipid microparticles, lipid nanospheres, lipid nanotubes, and nanostructured lipid carriers [13]. It should be noted that choose of bioactive delivery system is depended on some factors such as the solubility, stability of the bioactive compounds and their product applications.

Encapsulation is a method in which one component is surrounded by another material and produces particles with diameters of nano, micro, and millimeter sizes. The encapsulated components may be called in different ways such as the active agent, the base material, fill, internal phase, or payload phase. For instance, phytosomes and liposomes are encapsulating systems which are suitable in food and pharmaceutical

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applications. Phytosome is a technology developed by incorporating standardized plant extracts or water soluble phyto constituents into phospholipids to form complexes which leads to an increase in extracts' bioactivity and their antioxidant effect [14].

Emulsifiers, lipids, bilayer lipids, and non-bilayer lipids [13, 15] are considered as the main ingredients contributing to the preparation of lipid-based delivery systems.

One important factor in encapsulation technology is particle size which can be changed by different producing methods. The diameter of microcapsules ranges from 1 to 5000 μm. Nanoparticles, nanocapsules or nanospheres are particles with a diameters of 1 to 100 nm [16-18]. The particle size is an efficient factor on the transfer of bioactive compounds to different places inside the body [19-21]. Thus, compared to microcapsules, nanoparticles hold more potential for improving bioavailability, controlled release, and targeted delivery of bioactive compounds [22]. Furthermore, nanoencapsulation systems offer numerous benefits such as improved stability, protection against oxidation, preservation of volatile ingredients, taste masking, providing moisture-triggered and pH-triggered controlled release [3, 23]. In food science, this technology can change liquids and other ingredients into powders, making them simpler to process, and easier to use. Moreover, it can be used to improve the freeze and thaw ability of sensitive ingredients such as providing protection against moisture and cross contamination. In food products, the carrier material must be food-grade, and capable of surrounding the active materials [18].

Encapsulation includes the entrapment of food components, enzymes, cells or additional substances in tiny capsules [24-27]. Furthermore, this technique is used for living microorganisms such as probiotic bacteria which are important factors in production of functional foods in order to promote and maintain human health, but, this technique remains in microencapsulation systems [11, 12]. Also smaller particles enhance the spread ability and stability of food, and may contribute to the production of healthier low-fat food products [28]. Like in other sciences, encapsulation is employed in food science and technology; however, it is in its inception and call for further studies.

This review aimed to present different encapsulation techniques as well as controlled release mechanisms acquisition mainly for flavor such as mint by complex coacervation and bioactive ingredient like probiotics (*Lactobacillus*), by emulsification method.

2. MATERIALS FOR ENCAPSULATION

Encapsulation refers the technology employed for encapsulation of substances in miniature scales, that is, bioactive packing at mini scales [29]. Encapsulation is commonly used to preserve bioactive mixtures against unfavorable environmental factors, and monitor their release at the intended location [3, 13, 30].

The efficacy of nutraceuticals in impeding diseases relies upon conserving the bioavailability of the bioactive element until it reaches the intended site [7]. Decreasing the size of particles might enhance the delivery properties, the bioavailability, and solubility of nutraceuticals because of a larger surface area per unit volume [31]. Bioavailability of nutraceuticals can enhance due to the fact the nanocarrier permits it to flow into the bloodstream from the intestine straightforwardly. The size of nanoscale nutraceutical and the carrier accounts for their appellation as "nanoceutical" and "nanocarrier", respectively [32]. These compounds may be categorized as lipophilic and hydrophilic nutraceuticals as per their solubility in water. Ascorbic acid and polyphenols are examples of hydrophilic nutraceuticals [33-36]. Lipophilic nutraceuticals contain lycopene, beta-carotene, lutein, phytosterols, and docosahexaenoic acid (DHA) [33, 37-40]. For hydrophilic compounds, the release kinetics relies upon a proper arrangement of diffusion and erosion mechanisms, while lipophilic compounds often result in an imperfect release because of their poor solubility and low rate of dissolution by an erosion mechanism.[41-44] Moreover, lipophilic compounds permeate significantly well through the intestinal membrane via active transport and facilitated diffusion, while hydrophilic compounds permeate poorly, and only active transport mechanisms make their absorption possible [44, 45]. In addition, a bioactive compound is required to maintain its stability and biological activity by the time it reaches the intended location [3]. Nanoemulsions, nanoliposomes, solid lipid nanoparticles, and nanostructured lipid carriers are broadly utilized as lipid-based nanocarriers or nanodelivery systems which are employed in pharmaceutical, cosmetic, agricultural, and food industries [46, 47].

The ultimate characteristics of particles are determined by significant parameters such as the chemical and physical nature of the core and shell materials, evaluation of their interactions, and their proportion in the formulation of capsules [48, 49]. Natural polymers are the most suitable recommended source used in the formulation of nanodelivery systems [8].

3. ENCAPSULATION TECHNIQUES

Different encapsulation techniques are reported in following sections.

3. 1. Coacervation Coacervation is the modified emulsion and a relatively simple method. In coacervation procedure, core particles are wrapped by coating materials, and the separated from a polymeric solution. Coacervation might be caused when the surface energy of the core and shell materials are adapted through altering several parameters of the system such as temperature, pH, or composition. Next, the coating material is solidified through heat, cross-linking, or solvent removal techniques [50-52].

The microcapsules are often collected through filtration or centrifugation, being washed in a proper solvent, and consequently dried through some standard techniques such as spray drying, freeze drying, or fluidized bed drying to yield free-flowing, discrete particles [50-52].

This technique can be divided into two types: Simple coacervation referring to systems including only one polymer, and complex coacervation referring to systems possessing more than one polymer [52, 53]. Figure 1 illustrates the complex coacervation method. As two polymers are used in a specific pH with opposite charges; they are intertwined and form a coacervate .

For instance, complex coacervation system made of gelatin-arabic gum is recommended due to their abundance, biocompatibility, biodegradability and safe properties which were studied by our group [46]. The coacervate layer is transformed into a hard membrane through gelatin cross-linking. Formaldehyde or glutaraldehyde that can react with amino groups of gelatin are typically used as a cross-linkers. However, these aldehyde agents are toxic for human body and in food processing, which is regarded as one of the significant constraints for production of complex coacervation microcapsules for food and pharmaceutical industries [54]. Tannins, or plant polyphenols, can be used as a safe alternative cross-linker because of their ability to link with proteins, such as gelatin, through hydrogen bonding and hydrophobic interactions [46].

Complex coacervation, utilizing tannic acid as a hardening agent, was employed for preparation of the gelatin/gum Arabic microcapsules and encapsulating peppermint oil [46].

A hydrophilic coating, such as gelatin or gelatin-gum acacia, and water-insoluble core particles are required for the aqueous phase separation, which has been employed for encapsulation of citrus oils, vegetable oils, and vitamin A [46]. The resultant microcapsules might possess payloads of 85-90% and can release their contents by pressure, hot water or chemical reaction. The coating materials and core particles might be hydrophobic and water-soluble, respectively, in non-aqueous phase separation. This process has been considered for the encapsulation of solid food additives such as ferrous sulfate and menthol [55].

Encapsulation by coacervation may be classified into mononuclear and multinuclear capsules as per their internal structure. While the former are formed through encapsulation of one droplet of oil by coacervates, the latter are formed through aggregation among many mononuclear capsules [54].

3. 2. Spray Drying Spray drying is the oldest method of encapsulation. The first spray dryer was made in 1878 [56]. It is mainly utilized to encapsulate fragrance, oils, and flavors. Spray drying is a single step process in which a liquid product is transformed into powder in hot air [57]. Production stages of microcapsules by spray drying are as follow:

First, core materials are dispersed into wall materials, then the resulting suspension is fed into a spray drier to remove excess water [58]. This method is broadly utilized in industry because of its simple process and low cost but it has some limitations such as high temperature and the water based dispersion (the wall materials should be soluble in water) [59, 60].

3. 3. Spray Chilling Or Spray Cooling Spray cooling technology has been broadly utilized in the pharmaceutical industry, and food industry [61]. Cooling spray method has advantages such as mild processing conditions, good levels of maintaining volatile compounds, and probably large-scale production. This process is the same as spray-drying; nevertheless, the air needs to be of a lower temperature than that for spray drying. In spray cooling vegetable oils that have melting point in the range of 45-122ºC are used and the particles are insoluble in water due to the lipid coatings. The lipid coatings render the produced microcapsules insoluble in water, which is regarded as a drawback of spray cooling encapsulation, as such a disadvantage makes some of its applications difficult [61].

3. 4. Extrusion Extrusion Encapsulation is used to encapsulate volatile and unstable materials in glass carbohydrate matrix. The key benefit of extrusion encapsulation is the stability of flavors against oxidation, but thin-walled and pores formed during or after the process are considered as flaws of this method [62].

In extrusion encapsulation, a dual fluid stream of wall and core materials are first pumped through concentric tubes, then droplets are formed under the influence of vibration.

3. 5. Fluidized-bed Solid or porous particles are encapsulated through the fluidized-bed method [63]. In this technique, the solid particles are initially suspended in a gas stream, and then they are covered through spraying the liquid wall material; the fast evaporation

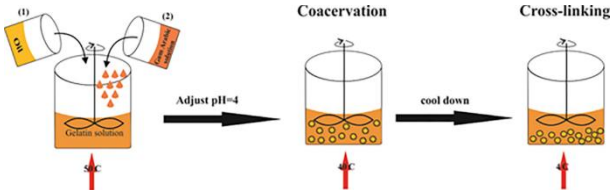

Figure 1. Process scheme of complex coacervation by using gelatin and gum Arabic

of solvent helps to form a layer on the surface of particles. This process continues up to the point the intended weight and thickness are achieved.

The fluidized-bed method is performed in three ways: top spray, bottom spray, and tangential spray. The bottom-spray and the top-spray are the most commonly used methods. But, top spray, due to its high versatility, high size of bed, and relative simplicity, top spray is recognized as the method with the highest probability of success in food industry [64].

3. 6. Emulsification Emulsification is the dispersion of a distinct liquid in a second immiscible liquid in the presence of emulsifier. By placing core materials in the first liquid, the active part can be encapsulated [56]. The emulsification process consists of two stages of transformation and distribution of particles by mechanical agitation. Then, the newly formed phase emulsion is stabilized by conversion of large particles into smaller particles through colloidal stirring or homogenization [65, 66]. However, it can be noted that the emulsification method has some weaknesses such as the wide distribution of particle size, no automated way and relatively large particle size (between100 to 200 µm).

In recent years, by combination of high-energy approaches such as high-speed or high-pressure homogenization and ultra-sonication, nanoemulsions with tiny droplet can be made [13]. The small droplet size offers nanoemulsion stability against sedimentation and creaming, along with a transparent or somewhat turbid appearance which is accurate for food applications [67] Lipophilic active agents such as β-carotene, plant sterols, carotenoids, and essential fatty acids can be encapsulated and delivered by O/W emulsion, whereas water soluble active agents such as polyphenols can be encapsulated by W/O emulsion [13, 68].

The fabrication of nanoemulsions can be classified into two high-energy and low-energy approaches; such a classification depends upon the underlying principle. While the former approach disrupts oils and aqueous phases into minute droplets by mechanical devices such as high-pressure homogenizers, micro fluidizers, and sonicators [13, 69]. In low energy approaches, nanoemulsions are developed as a result of phase transitions that happen during the emulsification process when the environmental conditions (either temperature or composition) are changed [13, 70].

Generation of disruptive forces higher than the restoring forces, which hold the droplets into spherical shapes, requires an extreme level of energy [13, 71]. In nanoemulsion, different properties such as the design of homogenizer (rotor-stator homogenizer, pressure homogenizer, ultrasonic homogenizer), homogenizer operating conditions (pressure, temperature, the number of passes or cycles, valve and impingement design, flow rate), environmental conditions (temperature), sample composition (oil phase, aqueous phase, surfactant concentration, and/or co-surfactant concentration), as well as its physicochemical characteristics determine the size of droplets [13, 72-74] The following two steps assist with the most efficient preparation of a nanoemulsion: first, conversion of separate oil phase and water phase into a “coarse emulsion” with approximately large emulsion droplet size (EDS) by rotor-stator devices [13, 75], then decreasing EDS by high-pressure systems [13, 76].

For high pressure nanoemulsion production, the coarse emulsions are delivered directly into the inlet of a high-pressure valve homogenizer. Generally, it requires extremely high pressure and various passes to produce nanoemulsions with the required EDS [77]. The disperse-to-continuous phase viscosity ratio ($\eta D/\eta C$) and the utilization of a suitable emulsifier are among the other factors determining the size of droplets [78, 79]. An increase in homogenization pressure and cycle led to a decrease in particle size and physical stability.

3. 7. Freeze Drying Freeze drying is also referred to as lyophilization. The freeze drying method is one of the most beneficial processes employed for drying thermo sensitive materials [80]. This process is based upon water crystallization. By crystallization of water, the non-frozen solution is sticky, and the spreading of flavor and fragrance is postponed [81].

Buffo and Reineccius[82] compared spray drying, tray drying, freeze drying and drum drying methods for encapsulation of orange oil by Arabic gum (GA) and modified starch. According to the obtained results, they found that freeze drying makes more desirable properties than other methods [82]. On the other hand, freeze-drying is a costly technology, particularly in comparison with the spray-drying method [83], because of which, freeze-drying is used as a second step to dry core materials previously encapsulated by other techniques [84]. As comparing these various methods of encapsulation, summary of positive and negative points of each technique are listed below in Table 1.

4. CONTROLLED RELEASE TECHNOLOGIES AND MECHANISMS

Microencapsulation of flavors and biomaterials in carrier matrices is widely applicable in food industry. Microencapsulation preserves the materials against desolate reactions, hampers the loss of volatile flavors, and improves the stability of the core materials of the flavor [85]. Numerous techniques, including coacervation, spray drying, spray chilling or spray cooling, extrusion, fluidized bed method, liposome entrapment, inclusion complexation method, centrifugal extrusion method, and rotational suspension separation, which were mentioned previously, are employed to develop the microcapsules [85]. Besides the principal means of stabilization and protection of flavors, and biomaterials, the controlled release of flavors and active materials from the capsule matrices appeared to be a beneficial and applicable process [86]. Accordingly, in our group the release characteristics of encapsulated l-menthol and encapsulated probiotics were studied by selected techniques and simulated environment.

4. 1. Determination of Release Profile of Coacervate L-Menthol Microcapsules in Simulated Digestive Fluids

Two different simulated digestive fluids, which were prepared as per US Pharmacopoeia, were utilized for exploring the release profiles of microcapsules: simulated gastric fluid (SGF, pH 1.2) prepared through dissolving 2 g of NaCl and 7 mL of HCl in distilled water with or without 3.2 g of pepsin and then diluted to 1 L, and simulated intestinal fluid (SIF) by dissolving 6.8 g of K_2HPO_4 and 190 mL of 0.2 (mol/L) NaOH in distilled water (SIF, pH 7.5) with or without 10 g of pancreatin and diluted to 1 L [94]. Precisely weighed quantities (~0.3 g) of microspheres were dipped in 40 mL of SGF, incubated for 2 h at 37 °C in a water bath by shaking at 100 rpm, transferred to 40 mL of SIF, and kept under the same condition for 6 h (Figure 2). As an example of this method, encapsulation of L-menthol which was investigated by our group is showed in Figure 2.

In order to determine the remaining amount of menthol, 0.1 g of microcapsule was dissolved in 1 mL of NaOH 2 (mol/L) and 2 mL of acetone containing benzyl alcohol, and then mixed by a Rota mixer for 1 minute [87]. The mixture was then placed at 90ºC water bath for 10 min. One microliter of acetone solution containing released menthol was analyzed by Gas Chromatography (GC) [44].

The release of L-menthol in the two environments, simulated gastric fluid (SGF) and intestinal fluid (SIF), were studied. Peppermint oil is prescribed for colon syndrome; thus, the release of menthol in the intestine is mainly desirable. The results presented that the release of menthol in the intestine is considerable. 50 % of menthol is released in SGF and over 40 % remained and was released in SIF. A timely and targeted release enhances the efficacy of food additives, increases the application range of food ingredients, consequently enhancing the cost-effectiveness for food manufacturers [29].

The following sections report some research studies on preparing different micro-particles and their release rates.

4. 2. Release from Coaservate Microcapsule

The author of this paper attempted to prepare coacervate microcapsules and investigate the peppermint oil release from wet and dry micro-particles in hot water bath and oven, respectively.

The cumulative release (η) of the microencapsulated peppermint oil was also calculated through the following formula, Equation (1):

$$\eta\,(\%) = (1 - V2\ /V1\ ) \times 100 \quad (1)$$

where V1 and V2 of peppermint oil were determined by Clevenger hydro distillation. The results of current study for wet particles demonstrated that the release profile of coacervate micro-particles relies on both core/wall weight ratio and water bath temperature. In addition, the data indicated two different phases in the release rate of peppermint oil from these microcapsules. The study on release in hot water bath revealed that the wet particles with a 1 : 2 core/wall weight ratio had only 20 % cumulative release after 60 min, which indicates suitable heat resistance characteristics; that is, the microcapsules are hardened adequately and are of a strong membrane with a three dimensional web

TABLE 1. Listed of various encapsulation methods for food ingredients including advantages and disadvantages of the methods

Method	Advantages	Disadvantages	Ref.
Coacervation	Simple	additional process	[46, 50-52]
Spray drying	Simple, low cost	High temperature	[58-60]
Spray chilling	Mild processing conditions	Water insoluble particles	[61]
Extrusion	Stability of flavors and volatile materials	thin-wall, high porosity	[62]
Fluidized bed	Desirable thickness and weight	Difficulties in performance	[63]
Emulsification	Suitable for wide range of materials	Wide distribution of particle size, no automated way	[64-68]
Freeze drying	Suitable for thermo sensitive materials	Costly technique	[80]

structure. Hence, the particles can be safe in hot water and have a gradual release of core material [87]. With regard to the two phases in the release rate, the results showed a notable decrease in release rate in the initial phase, while the release rate of peppermint oil reduced gradually in the next phase. These data also showed that the lower the core/well weight ratio in the initial phase, the lower the release rate. However, the release rate in the second phase increased with a decrease in the core/wall weight ratio. Moreover, an increase in core/wall weight ratio leads to an obvious rise in the loading capacity of microcapsules and particle size .

The influence of core/wall weight ratio on peppermint oil release using Design Expert Software to obtain the model for release kinetic. The results presented that the release of peppermint oil from microcapsules conformed to the first order release kinetics in hot water. The data also showed that the cumulative release of microcapsules at time t (Qt) notably reduced with a rise in the core/wall weight ratio, which is in agreement with findings obtained by other studies [88].

On the other hand, the release rate of peppermint oil from dried microcapsules in oven showed an invariable rate in the internal release. In dried micro-particles, due to the difference in vapor pressure between the inside and outside of microcapsules, while for wet coacervate microcapsules in hot water, the release of peppermint oil is based on the difference between concentration inside and outside the micro-particles [89]. It can thus be concluded that the dispersing medium was of substantial influence on the release of microcapsules. The obtained results showed that the cumulative release of dried microcapsules in the oven was more than that of wet microcapsules in hot water. However, Prata et al [90] reported that the release of the core material from coacervate microcapsules after drying was slower than wet microcapsules in ethanol .

Other group also investigated the release rate of peppermint oil from micro-particles with a different core/wall ratio in cold water; the obtained results showed two phases in release rate, exactly like that in hot water ($P > 0.05$). In the initial storage phase, microcapsules rapidly released the core material and the amount of cumulative release reached the largest value (about 7 %) within 10 days. But in the following 30 days, the release of microcapsules slowed down; that is, coacervate microcapsules were of superb storage stability. Moreover, the data showed that the effect of core/wall weight ratio on the release of coacervate microcapsules in cold water was not evident. The results obtained by the present study are in agreement with those of previous studies [91].

4. 3. Release of L-Menthol from The Spray-dried Powder Another study on preparing micro-particles was conducted by Soottitantawata et al. [92], which focused on encapsulation of L-menthol by spray drying method. They showed that retention of L-menthol depended on the initial solid concentration, and a decrease in the initial solid concentration increased its retention (the retention of L-menthol in the releasing test was determined as a ratio of the initial flavor amount). They also used the Weibull distribution function (Avrami's equation), can be seen as follow in Equation (2), to justify the shelf-life failure [93], and the release time-courses of the encapsulated flavors [94].

$$R = exp\ [-(Kt)^n] \quad (2)$$

where, t is the storage time, K is the release rate constant, R is the retention of L-menthol, and n is a parameter standing for the release mechanism. Moreover, the release rate was evaluated at various relative humidity (8-83 % RH) at a constant temperature (43ºC). The results showed that increasing the relative humidity increased the release rate.

4. 4. Nanoliposome Encapsulation by Ethanol Injection Method Combined with Dynamic High-Pressure Microfluidization (DHPM Method) Li-qiang Zou et al [95] studied the use of nanoliposome for Epigallocatechin gallate (EGCG) encapsulation. They combined dynamic high-pressure microfluidization (DHPM) through ethanol injection method to make particles [95]. Moreover, physicochemical characteristics of EGCG nanoliposome (EN) such as morphology, particle size, size distribution, zeta potential, and drug entrapment efficacy were investigated. In addition, encapsulation efficiency and polydispersity index of EN were characterized. They also investigated the drug release in PBS (pH 5.5, 0.05 (mol/L)) by considering EGCG solution (ES) as a control group [95]. Their obtained results showed that the encapsulation efficiency was 92.1±2.8 % under optimal conditions. The data also showed well sustained release profile of EN particles, which were 6.0 and 12.6 % EGCG released at 6 and 24 h; that is, it can be related to the presence of a galloyl group (a lipophilic group) and 8 hydroxyl groups in EGCG.[95]. In comparison with other previous studies, the results showed that the sustained release of EN was better than that of other nanoparticles [96,97]. It showed that nanoliposome was a suitable delivery apparatus for EGCG.

4. 5. Emulsification Method Here, as an example of this method, microencapsulation of *Lactobacillus* in sodium alginate-whey protein microcapsules which was studied by our group is reported [65]. In this study, viability of cells in gastric conditions as well as alive released cells in intestine conditions for free and encapsulated probiotics were studied. The release

mechanism from these microcapsules under gastric and intestinal simulated condition is presented in Figure 3. *Lactobacillus acidophilus* bacteria were encapsulated in sodium alginate-whey protein microcapsules, which were prepared by the emulsification method. Viability of cells in gastric conditions as well as alive released cells under intestine conditions for free and encapsulated probiotics were studied. For simulation of gastric juice, the MRS broth was adjusted to pH 2.0 with 1 (mol/L) HCl, and pepsin was suspended in the sterile MRS broth and kept in a shaker (100 rpm) at 37ºC to a final concentration of 0.3 % (v/v gastric juice (SGJ). In order to provide a neutral intestine environment, the MRS broth was set at pH 7 with sodium bicarbonate. The pancreatin solution was filtered through a 0.2 l µm sterile membrane filter, then suspended in sterile MRS broth to an ultimate concentration of 0.2 % (v/v) [66]. Nano-encapsulation of lactoferrin from calcium alginate was prepared through the oil/water emulsion method. Oil phase includes glycerol and tween 80, which was added to the aqueous phase including lactoferrin.

The suspension was stirred for 1 h at 800 rpm, and piecemeal was added to the alginate solution. The obtained compound was added drop-wise into $CaCl_2$ solution (0.5 % (w/v)) from a height of 10 cm and was kept for curing at 4ºC for 30 min. The obtained beads were separated for further release studies [98].

The release study was conducted by measuring the lactoferrin content within supernatant in time durations of 0, 30, 60, and 120 min. The results indicated that there was no release of lactoferrin from nanocapsuls, at the initial 30 minutes in two pH values of 2 and 7. This could be beneficial as lactoferrin would be kept intact under stomach conditions, and it can require simpler gastrointestinal conditions to be delivered safely into the target place.

It was obtained that the release of lactoferrin was controlled in all samples after 30 min. Thus, these nanocapsuls remain safe until 30 min at pH = 2. These obtained results conform to those obtained by other studies [99].

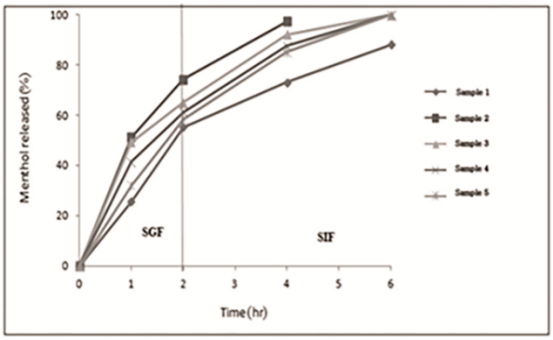

Figure 2. Effect of time on released menthol for different samples 1-5 in SGF and SIF (Sample1: Wall material: 3 %, Menthol: 3 %, Tannic acid: 1.5 %, Tween80: 0.08 %, Sample2: Wall material: 3 %, Menthol: 4 %, Tannic acid: 0.5 %, Tween80: 0.04 %, Sample3: Wall material: 3 %, Menthol: 5 %, Tannic acid: 0.75 %, Tween80: 0.02 %, Sample4: Wall material: 4 %, Menthol: 2 %, Tannic acid: 1.5 %, Tween80: 0.04 %, Sample5: Wall material: 4 %, Menthol: 3 %, Tannic acid: 1.25 %, Tween80: 0.02%)[46]

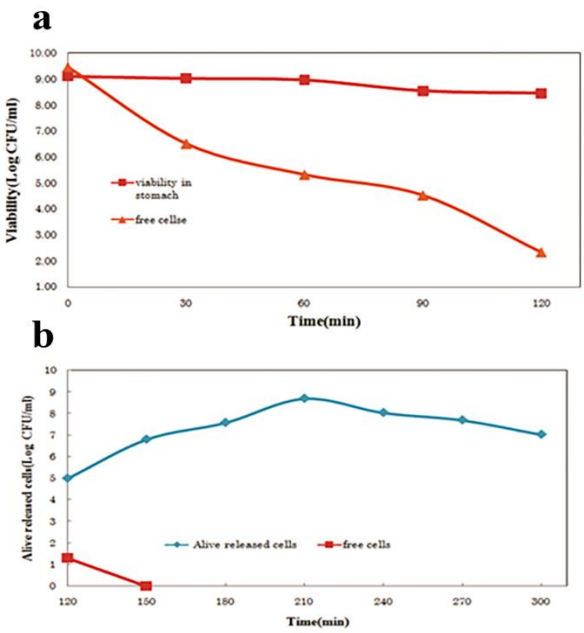

Figure 3. Viability and control release of cells in gastrointestinal conditions: (a) Viability of cells in gastric conditions, (b) Alive released cells in intestine conditions

5. CONCLUSION

Flavors' high volatility and whisker growth are serious problems for its applications and shelf life. Recently, the nano and micro encapsulation methods seem to be useful to solve these problems. Besides the initial means of protection and stabilization of flavors, a controlled release of flavors from the capsules seemed to be a useful method for releasing them as intended. Accordingly, this paper studied different encapsulation techniques for food and pharmaceutical delivery systems, and in the last part, it focused on the release properties and mechanism of encapsulated l-menthol in powder and oil forms; other food and bioactive materials were reported as well.

In addition, the authors reviewed different encapsulation techniques such as spray-drying, emulsification, nanoliposome encapsulation and coacervation. The spray drying method as the oldest

system of encapsulation, as well as the spray chilling method have been widely used in the pharmaceutical field and food industry. Extrusion encapsulation is used to encapsulate volatile and unstable materials in glass carbohydrate matrix. The primary advantage of extrusion encapsulation is the stability of flavors against oxidation. The fluidized-bed method is employed for encapsulation of solid or porous particles. Emulsification is the dispersion of a liquid in a second immiscible liquid in the presence of emulsifier. By placing the core material in the first liquid, the active part can be encapsulated. Here, microencapsulation of active biomaterials such as probiotics was mainly contrived by emulsification technique and its targeted release under simulated gastric condition was appraised. Among different methods, encapsulation through complex coacervation is one of the most studied and applicable systems. Capsules made through coacervation are heat-resistant, and are of well controlled-release properties based on mechanical stress, temperature, and sustained release.

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Encapsulation of Food Components and Bioactive Ingredients and Targeted Release

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چکیده

با توجه به اهمیت فناوری ساخت کپسول در فرایند های غذایی،دارویی وکشاورزی وتولید این ترکیبات،زمینه جدیدی برای هد فمند کردن این مواد بعنوان حامل های مواد فعال در غذا حاصل شده است.کپسول سازی می تواند به روش های مختلفی مانند کو سرواسیون ترکیبی، امولسیون سازی،جدا سازی فاز ها، خشک کن پاششی ،خشک کن دمایی وخشک کن سرمایی ،اکستروژن پوششی، خشک کن انجمادی، بستر پوششی، استفاده از سیستمهای لیپزومی، جداسازی با روش سانتریفیوژ، کوکریستالیزاسیون و روش های مولکولی انجام شود. کپسوله کردن روشی است که در آن یک یا چند ماده ی زیست فعال با استفاده از مواد دیگر پوشش داده می شود. این روش بمنظور حفاظت، جداسازی و کمک به نگهداری و رهایش کنترل شده مواد استفاده می شود. رهایش زمان بندی شده و هدفمند موجب بهبود عملکرد ترکیبات و کاربرد آنها می شود. بعلاوه در بهینه بودن دوز مصرفی و ارتقای هزینه های فرآیند تولید موثر است. در این مقاله تحقیقات و نوآوریهای اخیر در زمینه ی کپسوله کردن و تکنولوژی رهایش کنترل شده جمع بندی شده است. بعلاوه اصول طراحی سیستم رهایش برای روغن نعناع با استفاده از تکنیک کوسرواسیون و روش میکروامولسیفیکاسیون برای کپسوله کردن مواد زیست فعال و رهایش هدفدار لاکتوباسیلوس کپسوله شده ، گزارش شده است.

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