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Review Article

A systematic review of encapsulation and control release technology in food application

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Abstract

This review paper is aims to give a brief description of encapsulation and control release technology in food preservation. Besides the material give potential information for those who interested for future development perspectives of the sector and also create awareness potentially for readers, traders, Students, factory workers, technologist and related stakeholder. the selection of encapsulating materials depends on the types, origins, and properties of these food ingredients. It is being increasingly popular in pharmaceutical, nutraceutical and functional food industries as a highly effective method that performs various functions; the major being prolonging the shelf-life of the active, masking the undesirable flavour, colour and taste and controlling the release of bioactive.

Introduction

The substance that is encapsulating is referred to as the coating, membrane, shell, capsule, carrier material, external phase, or matrix [1,2]. Also, controlled release defined according to the European Directive (3AQ19a) as a "modification of the rate or place at which an active substance is released." Such a modification can be made using materials with specific barrier properties for manipulating the release of an active and to provide unique sensory and/or functional benefits. Addition of small amounts of nutrients to a food system, for example, may not affect its properties significantly; however, incorporating high levels of the nutrient either to meet certain requirements or to treat an ailment will most often result in unstable and often unpalatable foods. Examples of such nutrients include fortification with calcium, vitamins, polyunsaturated fatty acids, and so on, and the associated grittiness, medicinal and oxidized taste, respectively. Different types of controlled-release systems have been formulated to overcome these challenges and to provide a wide range of release requirements. The two principal modes of controlled release are delayed and sustained release.

Delayed release is a mechanism whereby the release of an active substance is delayed from a finite "lag time" up to a point when/where its release is favored and is no longer hindered. Examples of this category include encapsulating probiotic bacteria for their protection from gastric acidity and further release in the lower intestine, flavor release upon microwave heating of ready-meals or the release of encapsulated sodium bicarbonate upon baking of a dough or cake batter.

Sustained release is a mechanism designed to maintain constant concentration of an active at its target site. Examples of this release pattern include encapsulating flavors and sweeteners for chewing gum applications so that their rate of release is reduced to maintain a desired flavor effect throughout the time of chewing. A wide range of cores (encapsulants), wall-forming materials (encapsulating agents), and technologies for controlling the interactions of ingredients in a given food system and for manufacturing microcapsules and microparticles of different size, shape, and morphological properties are commercially viable. Therefore, the objective of this material is to Provide brief overview to the basic understanding and common process to encapsulate food active agent and control release system in food processing.

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Methods

This portion of scientific reports conducted on related to encapsulation and control release in food application. The initial review served to introduce and frame the issue of the keywords on the Encapsulation; Food Preservation; Control Release; Technology; future potential.

Wall-forming materials

Carbohydrates: Starch and starch derivatives for instance maltodextrin, cellulose derivatives for instance carboxymethyl cellulose, gums for instance gum Arabic, guar gum and chia seed gum and β-cyclodextrin are the most commonly used carbohydrate-based wall materials. This is because of their abundant availability, excellent core protection ability, bland flavour, these wall materials are used to encapsulate diverse food materials such as oxygen sensitive and PUFA-rich oil, vitamins, proteins & bioactive peptides, enzymes and flavour [3-5]. Modified starches are produced by inducing side chains of lipophilic succinic acid to increase the emulsifying ability of starch. Moreover, Modified starches are found to show better protection than native and waxy starch [6] and offer exciting emulsion stability [7].

Proteins: Superior functional and physicochemical properties including gel forming ability, emulsifying capacity and film formation capability make protein an excellent encapsulating material which find huge applications in food industries [8,9].

Gelatin is the widely used shell matrix used to manufacture highly stable soft gels of omega-3, vitamin D and fish oil. Milk proteins such as sodium caseinate and whey protein isolate, and other plant proteins such as soy proteins, pea proteins have been used as wall materials for several years. Whey protein has also been reported as fantastic wall materials for encapsulating sensitive flavours and PUFA-rich oils. This protein possesses excellent encapsulation efficiency (up to 89.6%) over other proteins such as soy protein (up to 75.9%) [10,11]. The authors found that resultant microcapsules recovered by spray drying remain stable over 60 days at high water activity (aw = 0.74-0.90) [11]. One of the major limitations of using protein as encapsulants is their allergenicity to some individuals.

Wheat protein (e.g., gluten), Soy proteins, and peanut proteins are reported to be highly allergenic to a number of individuals. This not only limits their application but also warrants manufacturer declaration on the label for their presence in the designed foods. In addition, proteins are sensitive to structural changes and their effectiveness as wall materials is greatly dependent such as pH, ionic strength and temperature of the emulsions or solution [11]. Even Hough, blending these proteins with other materials, particularly carbohydrate-based biopolymers, such as maltodextrin, corn syrup solids and lactose has been reported to be an effective method to minimize environmental effect on their functionality as encapsulants [12,13].

Lipids: Since lipids are hydrophobic materials and are insoluble in water and hence, they are widely used to encapsulate hydrophilic substances. Many different types of lipids including phospholipids, glycerides, fatty acids and waxes have been explored for their ability to encapsulate food actives [1]. Although lipid-based encapsulation technology is relatively new and emerging field, it is becoming highly popular as a means of delivering pharmaceutical, bioactive food and nutraceutical ingredients. Main types of lipid-based delivery systems are four: nano emulsions, nanoliposomes, solid lipid nanoparticles and nanostructure lipid carriers [14].

Release trigger

Encapsulation and controlled-release systems can be designed to respond to one or a combination of triggers that can activate the release of the entrapped substance and to meet a desired release target or rate. Triggers can be one or a combination: Temperature: fat/wax matrices; Moisture: hydrophilic matrices; pH: enteric coating, emulsion coalescence, and others; Enzymes: enteric coating as well as a variety of lipid, starch and protein matrices; Shear: chewing, physical fracture, and grinding; Lower critical solution temperature of hydrogels.

Discussion

Ingredients types

The types of food ingredients that can be encapsulated are shown in Table 1 below.

Processing technology of encapsulation and control release

Microwave combination technology: food products heated by MW shows better retention in color, texture, and flavor compared with conventionally treated products, MW heating is associated with numerous problems, such as non-uniform heating, partial overheating, and limited penetration [16,17]. Conventional methods such as vacuum drying (VC) and hot air (HA) heating can preserve the quality of perishable agricultural products without any damage during processing; however, it takes considerable time and consumes more energy with low energy efficiency to complete the processing [18]. MW technology combined with the aforementioned conventional methods has been investigated particularly in drying and baking processes.

Table 1: Various food ingredients that can be encapsulated [15].

Type of ingredient	
Flavoring agents such as oils, spices, seasonings and sweeteners	Leavening agents
Acids, alkalis, buffers	Antioxidant
Lipids	Preservatives
Redox agents (bleaching, maturing)	Colorants
Enzymes and microorganisms	Cross-linking and setting agents
Artificial sweeteners	Agents with undesirable flavors and odors
Essential oils, amino acids, vitamins, minerals	

Infrared radiation combination technology: IR heating is considered a promising method especially for drying processes, observed problems in IR drying include scorching heat on the surface of food products and a limited IR penetration depth [19]. Case hardening is a troublesome problem occurring in conventional HA drying process because the surface of food material is dried first, and as drying process progress, the dried surface of food becomes a barrier to heat transfer [18]. To prevent undesirable phenomenon caused by either IR or conventional heating methods, a number of studies on dehydration of food products using integrated IR and conventional methods have been conducted. IR-assisted HA drying processes for fruit and vegetable has been evaluated and developed [20,21].

High-pressure processing combination technology: High-pressure processing (HPP) has been mainly applied to pasteurize liquid food products; however, it often times could not inactivate bacterial spores (e.g., Bacillus and Salmonella) which are heat and acidic resistant [22]. Therefore, thermal treatment has been applied to HPP as a pretreatment step. The effectiveness of HPP combined with thermal treatment on the inactivation of PMEs and the inactivation kinetics in various agricultural products were evaluated by a number of researchers [23].

Radio frequency electric field combination technology: Ukuku and Geveke [24] developed a combined UV light and RF electric field (RFEF) system to inactivate Escherichia coli K-12 in apple juice. Apple juice was preheated up to 25, 30, and 40 ºC and then treated by individual UV, RF and combined UV with RF treatment. After all treatments, apple juice samples inoculated with microbial contaminant were analyzed for leakage of UV-absorbing substances as the function of cell membrane injury. The individual UV and RFEF treatment at 40 ºC showed the minimum surviving population of E. coli K-12 in the juice. A higher bacterial inactivation was expected when the two treatments were combined; however, the determined number was only an approximately 0.6 log microbial reduction higher than UV treatment alone. Although inactivation of E. coli K-12 in apple juice was not influenced by the combination system, UV-absorbing substances determined in the juice treated by combined treatment was substantially different from individual UV treated sample. The results suggested that combination treatment would damage bacterial cells and lead to more leakage of intracellular UV-absorbing substances than individual treatment.

Combined RF with HA treatment was investigated to improve the quality and mold control of enriched white bread [25]. Prior to RF–HA treatment, the bread columns inoculated with mold spores were kept under a sterile hood in order to equilibrate moisture content in the breads. Additionally, target HA and treatment temperatures controlled by an electrical fan heater and RF power were evaluated to maximize the mold lethal condition. Visible mold growth was observed from the surface of untreated bread loaves stored for five weeks at room temperature; on the other hand, mold was found in the sample after an extra four weeks using the combined RF–HA treatment. Moisture migration from the bread crumb to crust was caused by generation of internal vapor pressure during the RF heating. The consequent moisture loss in the bread crumb and increased moisture at the crust led to a more even distribution of moisture in the treated bread samples. Combined RF and HA treatment had little effect on the water activity of breads during storage.

Pulsed electric field combination technology: Synergistic effect of combined thermal treatment and pulsed electric field on inactivation of microorganisms in liquid food products has been investigated by a number of researchers [26,27]. In these studies, liquid food products (such as salad dressing, liquid whole egg, liquid egg york, apple juice, fruit smoothie-type beverage) pretreated using a heat exchanger, heating coil, or hot water bath at different temperatures were sequentially applied to the pulsed electric field treatment. The effect of sequential thermal treatment and pulsed electric field treatment on inactivation of microbial contaminants, i.e., Lactobacillus plantarum, Escherichia coli O157:H7, Salmonella enteritidis in respective salad dressing, liquid whole egg, and liquid egg yolk was also investigated [26,27]. Prior to pulsed electric field treatment, the liquid food product was preheated up to a certain temperature in the hot water bath. Preheated sample flowed between two disk electrodes and then through an electric field with a range of 9–15 kV/m with different pulse numbers and high frequency. The pulse width and frequency were adjusted using external transistor–transistor logic with a frequency trigger. Increasing the pretreatment temperature of liquid food product (apple juice and liquid egg yolk) and higher electric field strength had a significant effect on the inactivation of peroxidase, polyphenol oxidase, and E. coli O157, as well as, lower D-values [26].

Ohmic heating combination technology: Combined ohmic and plate heating system for cooking hamburger patties was developed for the enhancement of physical properties of the patties [28]. A domestic plate grill was modified for the combination system. The plate was preheated first and then 50 V of alternating current was applied for OH. The required cooking time was determined to be 117 and 163 s for the combined and conventional techniques, respectively. The elasticity index of the conventionally cooked meat has a slightly higher value than that of cooked meat by ohmic–plate heating. This suggested that the meat cooked by the combination system would be less chewy. Otherwise, the mechanical properties of the meats cooked by individual plate and OH methods were very similar. The application of OH for cooking of hamburger patties did not affect the taste and texture of the meat.

Future perspective (development potentials)

Encapsulation technology has been used in various industries for more than seven decades, there have been several advancements in both the science as well as the practical application of this technique since its first commercial application in 1950. It is being increasingly popular in pharmaceutical, nutraceutical and functional food industries as a highly effective method that performs various functions; the major being prolonging the shelf-life of the active, masking the undesirable flavour, colour and taste and controlling the

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release of bioactive. Encapsulation methods for new bio-actives are being explored and research advancement is underway to improve the process and product characteristics.

Innovative food-grade encapsulants are being explored to reduce the production costs and meet other technical specifications and consumer expectations. With the escalating demand of functional foods including omega-3s, probiotics, vitamins and phytochemicals, these functional ingredients are being incorporated into wide range of products such as breads, milk, fruit juices, tortillas, chocolate, yoghurt drinks, spreads, peanut butter, eggs and meat. Accordingly, various methods of microencapsulation of different bioactives have been developed. At present, spray drying-based microencapsulation method is being widely used in various industrial applications; however, more advanced methods including complex coacervation are gaining increased attention in recent years. Complex coacervation technology has been reported to receive a high product yield and the resultant product possesses prolonged stability even at a very high payload (up to 99%). In addition, it yields products with lowest unit product cost [29]. The biggest disadvantage of this technology is limited availability of shell materials. So far, gelatin is the only protein which is successfully used in commercial scale.

A number of studied have reported that the plant proteins are capable of forming coacervates in the presence of polysaccharides [19,30]. This corroborates that plant proteins can be used instead of animal proteins in complex coacervation process. Reference [31] used α-gliadin (cereals) and pea globulin (legume) in complex coacervation process. These authors found that both these proteins form excellent complex coacervates with the gum Arabic. However, the application of α-gliadin in the coacervation process will not achieve widespread acceptance as this protein is associated with some kind of allergenicity in some individuals [31]. So, there is a need to test other plant polysaccharides for their potential as encapsulating and delivery vehicles of active ingredients. There are certain characteristics which are looked for before using a biopolymer as an encapsulant. Among them are emulsifying and interfacial properties, film forming abilities, solubility and gel-forming properties. Emulsifying properties of flaxseed protein, chia seed protein and lentil protein have been evaluated in recent years [30,32]. It was found that emulsions stabilized by Flax Protein Concentrate (FPC) at neutral pH and in the absence of salt had a smaller droplet size and higher surface charge which makes them good candidates to be used in coacervation process. FPC-stabilized emulsions were more stable against the effect of salt concentration.

The FPC can be effective stabilizing emulsions where droplet size and zeta-potential are major factors influencing the emulsion stability. Flaxseed gum is also found to possess good potential in stabilizing the protein-based emulsions. Encapsulating unstable and bioactive core materials with a protein-gum complex shell matrix isolated from the same plant source is a very recent idea of microencapsulation. Reference [32,33], successfully encapsulated flaxseed oil (core) by novel matrix of flaxseed protein-flaxseed gum complex coacervate. Similarly [30] successfully encapsulated chia seed oil using chia seed protein-gum complex coacervate shell matrix. The authors have compared the effectiveness of protein only and gum only shell matrix with the complex coacervate shell matrix and concluded that complex coacervation based shell matrix is more effective over the other two. However, this laboratory experiments need further study for their effectiveness and reproducibility in pilot plant or commercial trials.

Conclusion

There are various reasons of encapsulation, many bioactive ingredients are encapsulated to enhance their longevity and functionality. Several bioactive ingredients are encapsulated to prevent their degradation from environmental stressors and control their release in the gastrointestinal tract. For example, baking yeast and dough conditioners are encapsulated to increase their performance or to overcome other processing challenges. It has been reported that uncoated chemical leaveners release carbon dioxide prematurely. This is even more prominent in warmer environments. In addition, ingredient degradation or flavour loss during the baking process can occur in systems where uncoated ingredients are used. Therefore, encapsulation method is dependent on the nature of core material and intended use of the final product. As a consequence, various methods of encapsulation are developed.

Coating substances that are basically film forming materials can be selected from a wide variety of synthetic polymers or natural, depending on the characteristics desired in the final microcapsules the material to be coated. The coating composition is the main determinant of the functional properties of the microcapsule and of the method to be used to improve the performance of a particular ingredient. An effective coating material should have good rheological properties at high concentration and ease of manipulation during the process of encapsulation and also, selected so that it produces a stable emulsion or dispersion with the active ingredient, and does not react or degrade the active material during processing and storage. Beside this, it should meet specified or desired capsule solubility properties and active material release properties.

Coating materials for encapsulation of food ingredients can be subdivided into cellulose, gums, lipids, and proteins. Core materials include flavors, nutraceutical, antimicrobial agents, and therapeutic actives, vitamins, alkalis, buffers, sweeteners, minerals, antioxidants, colors, acids, nutrients, enzymes, cross-linking agents, yeasts, chemical leavening agents, and so on. For instance, encapsulation by extrusion and spray drying depends primarily on the carbohydrates used for the encapsulation matrix. Furthermore, Gums usually used as control crystallization, texturing ingredients, stabilize emulsions, and inhibit syneresis (the release of water from fabricated foods), thereby improving coating properties. Lipids are generally used for encapsulation for water soluble ingredients. Protein ingredients are also effective in encapsulating food ingredients. In particular, gelatin is used in coacervation.

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