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Research Progress On The Composition, Preparation And Application Of Microcapsule Technology

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Abstract
Microencapsulation technology uses film-formable polymer compounds to encapsulate a solid, liquid, or gaseous core material that needs to be protected to form tiny droplets with one or more layers of composite film on the outside. It does not react with the core material substance and has appropriate mechanical strength, solubility, fluidity, emulsification, permeability, and stability. In addition, the choice of wall material can modulate the release properties of microcapsules. In this paper, the main components of microcapsules are reviewed, and the standard methods for the preparation of microcapsules and the progress of their application in the food field are described in detail to provide a reference for the further application of microcapsule technology and process optimization.

Keywords: *microencapsulation technology; composition; preparation; application progress*

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I. Introduction

Microcapsule technology is an ideal micro-embedding technology for storing substances, which usually uses natural or synthetic polymer materials as the wall material and covers the surface of the core material through the form of a film to form a microcapsule with a diameter of 1~5000 nm, which isolates the core material from the external environment and releases the target core material under a certain period or under a specific environmental condition, which can play the roles of protecting the core material, controlling core material release, enhance the stability of the core material and improve the utilization rate of the core material [1-2]. Microencapsulation can establish a functional barrier between the core and wall materials, avoiding chemical and physical reactions and maintaining the bioactivity and physicochemical properties of the core material [3]. Microencapsulation of the core material by microencapsulation technology slows down molecular diffusion so that the properties of the target substance can be retained for a long period [4], and microencapsulation of food products is a measure to make them more stable [5].

With the continuous development of society, people pay more and more attention to the stability, nutrition, and safety of food [6]. To meet this demand, more and more researchers have begun to engage in the research and development of microencapsulation technology to promote the rapid development of microencapsulation technology. This paper aims to textually review the main components of microencapsulation technology and standard preparation methods to highlight its application in food delivery. It discusses the application of microencapsulation technology in food, which is currently used in bioactive ingredients, beverages, meat products, and additives. The above studies are conducted to provide a basis for further application and process optimization of microencapsulation technology.

II. Shell Composition Of Microcapsules

Microcapsules are divided into two main parts: core material and shell material [3]. The material embedded in the microcapsule is called the core material, which can be classified as oil-soluble, water-soluble compounds or mixtures according to the difference in solubility [7], and its state can be solid-liquid-gas in any one state. The performance of microcapsules depends mainly on the selection of shell materials because different shell materials directly affect the physical and chemical properties of microencapsulated products. Suitable shell materials can significantly improve microcapsules' encapsulation effect, encapsulation rate, and stability [8]. Ideal microcapsule shell materials should not react with the core material and should have appropriate properties such as mechanical strength, solubility, fluidity, emulsification, permeability, and stability [9]. In addition, the choice of shell material can modulate the release properties of microcapsules. Therefore, several commonly used shell materials for microencapsulation are summarised below.

Natural Shell materials

Natural polymer materials are ideal shell materials for microcapsule preparation due to their excellent film-forming properties and stability. Since most natural polymer materials are non-toxic and have excellent biocompatibility [10], they have been widely used to prepare protein microcapsules. These natural microencapsulated shell materials are classified into carbohydrates, proteins, and lipids [11]. Among these shell materials, carbohydrate-based, such as sodium alginate and chitosan, are widely used, while lipid-based shell materials are relatively more limited.

Artificial Shell l materials

Currently, commercially available microencapsulated products mainly use natural polymeric compounds as shell materials, most of which are polysaccharides and protein molecules that can be absorbed by the human body [12]. However, under extreme external environments, these natural polymeric compounds are prone to denaturation or microbial decomposition, leading to premature release of the core material. In order to expand the broad application field of microcapsules, researchers have started to use modified natural polymer compounds to construct shell materials to compensate for the shortcomings of natural polymer materials and to fully utilize the advantages of semi-synthetic and fully synthetic polymer materials [13]. Introducing these modified polymeric materials provides new possibilities for developing microencapsulation technology and enhances the stability and functionality of microcapsules in different applications.

III. Microcapsules Preparation Method

Spray drying method

Spray drying technology is one of the most widely used and oldest methods, mainly used for drying solutions, dispersed phases, and pastes to produce granular materials [14]. Spray drying is the microencapsulation of bioactive compounds in a product, controlling the delivery of beneficial compounds to the host and opening up new possibilities [15]. This method is commonly used to protect various bioactive compounds from degradation, control or delay the release, and mask unpleasant tastes or odors [16] while saving potential costs, making it cost-effective. Although spray drying is a low-cost microencapsulation technique, more research is needed on co-encapsulation, possibly due to the negative impact that high temperatures can have on bioactive stability. Therefore, in practice, it is necessary to improve the survival of the core by optimizing the spray drying conditions and using anti-thermal protectants, e.g., using lower import and export temperatures can reduce its thermal damage, and microcapsules prepared by this method have a more homogeneous shape, better spherical shape, and smaller particle size (usually less than 100 um).

Guo et al [17] used soluble small molecule soluble starch obtained from corn starch by pasteurisation and centrifugation methods to encapsulate oil independently by spray-drying method under 2:1 conditions of wall and core materials. The encapsulated oil of these microcapsules can be released slowly under the action of a-amylase and amyloglucosidase, and has high encapsulation rate, high stability, and high solubility in boiling water.

Freeze-drying method

The principle of the freeze-drying method to protect the core material is based on sublimation, which is mainly divided into three steps: freezing, preliminary drying, and secondary drying. Usually, the prepared microcapsule solution is first frozen in a refrigerator at -80°C, and then dried by sublimation directly under high vacuum conditions [18]. Freeze-drying can overcome the disadvantages of spray-drying because the conditions are relatively milder than spray-drying [19], and the survival rate of microencapsulated probiotics obtained by freeze-drying is usually higher. However, during freeze-drying, cell membranes are often damaged due to the formation of ice crystals.

Ledri et al [20] explored the effect of maltodextrin and isolated whey protein on chlorophyll encapsulation using spray drying and freeze drying methods, respectively. It was found that the microcapsules obtained by freeze-drying method had smaller particle size (1.087-0.165 um) and higher c-potential (10.6-18.3 mV). And the freeze-drying method was more effective in protecting the chlorophyll from pH changes and light.

Composite cohesion method

The composite cohesion method is the use of two kinds of polymer materials with opposite charges as a composite wall material, the core material uniformly dispersed by changing the pH, temperature, or solution concentration of the system so that the two wall materials interact with each other to form a kind of complex, resulting in a decrease in the solubility of the system, so as to coalesce and precipitate the formation of microcapsules of the process [21]. The preparation of microcapsules by the complex coalescence method is mainly divided into four parts: firstly, determine the optimal reaction ratio between the two wall materials with opposite charges; secondly, add the core material to one of the wall material solutions to mix the two thoroughly, so as to make them evenly dispersed; then, add the other solution with opposite charges, and at the same time, adjust the pH of the whole solution system, so as to make the two wall material solutions with opposite charges; finally, the system produces a cohesive layer of gelation and solidification, forming microcapsules. Complex coalescence is an up-and-coming technique for microcapsule preparation in the food and pharmaceutical fields, with the advantages of high loading and high encapsulation efficiency (up to 99%), relatively low processing costs, and the ability to synthesize at room temperature using food-grade shell materials to complex coalescence of active compounds, which makes it a suitable choice for the food and agrochemical industries [22].

Complex coagulation in food ingredient encapsulation mainly involves the use of two types of oppositely charged protein and polysaccharide polymers, both of which can form complex shells around the core material [23], proteins from animal or plant proteins, and polysaccharides, also from natural sources, are good candidates for microencapsulation by complex coagulation. For example, microencapsulation of hydrophobic substances is often carried out by complex coagulation, which is a mild preparation process with safe reaction conditions [24]. Compared to microcapsules obtained by conventional spray-drying, microcapsules obtained by complex coalescence have higher loading and protect the hydrophobic material from the external phases of the wall [25].

Emulsification microcapsule technology

The emulsification method [26] is to mix the core and wall materials of microcapsules into one system, add a cross-linking agent so that the wall material first reacts with the cross-linking agent to form a specific structure to wrap the core material, and then add emulsifier and other dispersed phases to form microcapsules further. The representative technology is Pickering emulsion technology [27]; the advantage is that the addition of an emulsifier and the more convenient control of time can achieve a precise grasp of the operation process. However, the shortcomings are that adding an emulsifier requires the elution of the oil phase, which requires a large amount of material, for the production cost can't be effectively controlled, and the technology needs to be further improved.

Extrusion method

The extrusion method usually involves extruding a mixture of probiotics and hydrophilic colloids as small droplets into a gel or hardening solution such as CaCl2 to form microencapsulated particles through an extruder or syringe needle [28]. Microcapsules prepared using this method can maximize the preservation of probiotic cellular activity [29]. This method is widely used for the co-encapsulation of probiotics with high viability due to its simple equipment, lower cost, and mild reaction conditions.

Zhang et al. [30] co-embedded Bifidobacterium pseudo-small chain G7 with nanoemulsion by extrusion method using sodium alginate as the wall material and obtained microcapsules with an average particle size of 729 um, which showed an elliptical shape and had a better protection effect on probiotics under gastrointestinal conditions. Li et al. [31] embedded Lactobacillus casei by extrusion method using sour date pericarp polysaccharides and sodium alginate as the wall material and produced microcapsules with a particle size of (2.69±0.09) mm, which can effectively improve the activity of probiotics. However, the particle size of microcapsules prepared by this method is usually larger, 0.05-3 mm, which makes them less palatable when applied to food products, and there are disadvantages such as more investment in equipment, lower yield, etc., and they only exist in the laboratory stage, which is not suitable for large-scale production [31].

IV. Application Of Microencapsulation Technology In The Food Field

Application of microencapsulation in bioactive substances

Bioactive substances such as oils, proteins, polyphenols, lipids, and other food components have special physiological functions such as regulating the organism, enhancing immune function, antioxidant, antibacterial, anti-inflammatory, preventing cardiovascular disease, etc. [32-33], but such substances are often affected by their structure and composition, and there are problems such as poor solubility, poor stability, and low bioavailability, which makes the application of such substances in the food industry restricted [34]. In order to improve the stability of biologically active substances, people often use microencapsulation technology to encapsulate these biologically active substances, which can enhance the stability, solubility, and bioavailability of the active substances. Li et al. [35] studied the effect of microencapsulation on the stability of mulberry polyphenol processing. They found that the use of microencapsulation to encapsulate can significantly improve the stability of plant polyphenol light stability, thermal stability, and storage stability.

Microencapsulation in beverage applications

Microencapsulation technology in the beverage industry is remarkably rapid development. However, the dairy products added to the Lactobacillus active substances in the role of a short period for the production of room temperature dairy products have significant limitations. In the case of room temperature storage, probiotics in dairy products rapidly lose their activity [36]. In contrast, probiotics are embedded to improve the antioxidant capacity of the product, applied in yogurt with the best slow release, directly affecting the prospects for the development of the relevant microencapsulation in dairy products. Burcu et al. [37] investigated the microencapsulation of Streptococcus thermophilus strain CCM4757 in chocolate milk in terms of microcapsules' viability and storage conditions. According to the study, Streptococcus thermophilus can be considered a potential probiotic microorganism [38]. Burcu et al. added microencapsulated Streptococcus thermophilus strain CCM4757 and non-microencapsulated Streptococcus thermophilus in experimental groups to simulate the passage of the human digestive system through saliva, gastric fluid, and intestinal fluids, and the results proved that microencapsulated Streptococcus thermophilus strain CCM4757 has a strong survival ability. At this stage, the range of foods containing probiotics on the market has expanded from dairy products to meat, cereals, fruits, and chocolate [39], which have more applications in food.

Protecting hydrophilic compounds in food applications is a major challenge as they are highly susceptible to leakage from the capsule into the aqueous phase. The use of alginate and chitosan prepared via W/O emulsion to protect microcapsules of hydrophilic compounds [40] was distinguished from the conventional hydrogel bead method for the preparation of microcapsules of hydrophilic compounds [41] by the good polydispersity of alginate/chitosan microcapsules prepared at alginate to chitosan ratio of 7:5. This technique improves the anticorrosive effect of microcapsules in water, which can protect the hydrophilic compounds in food products and simplify the previous microcapsule production techniques.

Application of microcapsules in meat products

Meat products are susceptible to spoilage during production and processing or to grey meat and dry and hard meat with high post-slaughter pH due to improper storage conditions, which affects sales and consumption. The three leading causes of spoilage are the nature of the meat product, environmental factors, and microbial contamination. Encapsulation of antioxidants or other substances in meat products by means of microencapsulation can effectively improve the antioxidant and resilience of meat products, prolong the storage and shelf life, and, most importantly, increase yield and efficiency. Carlos et al. [42] evaluated the effect of the addition of microencapsulated fish oil to hamburger meat on the savory flavor, and the addition of the fish oil in the form of microencapsulation in conjunction with cooking methods increased the salinity of the burger meat and increased the omega-3 levels. Increased the intake of omega-3 unsaturated fatty acids, savory presentation, and consumer acceptance of the burger. Microcapsules were prepared using spray drying technology with maltodextrin and chitosan as the wall material and fish oil as the core material, starting with the preparation of oil-in-water emulsions. Recently, researchers have developed fish oil microcapsules added to different meat products to increase the fish oil (docosahexaenoic acid) content of the meat products, to improve the nutrition of the meat products as well as to enhance the perception of salty flavor in savory derivatives.

Application of microencapsulation in food additives

Cloves and aniseed, as medicinal and food herbs, can be made into microcapsules and added to secondary processed meat products as antimicrobials and preservatives. For example, the essential oil of star anise (SAEO) was encapsulated using its strong antimicrobial activity against important food pathogens such as Escherichia coli (E. coli), Staphylococcus aureus (S. aureus), and Acinetobacter baumannii (A. baumannii), as well as the special aroma of the essential oil of star anise [43]. Electrostatic complexation using rice protein pectin yielded.

V. Conclusion And Outlook

Microencapsulation technology has received significant attention due to its excellent properties, high encapsulation rate, stability, good solubility, and other behaviors. This paper reviews the main components of microencapsulation technology and standard preparation methods to highlight its application in food delivery. The application of microencapsulation technology in the food sector is discussed, and microencapsulation are currently used in bioactives, beverages, meat products, and food additives. In the future, the preparation process of microencapsulation technology should be further optimized to establish an ideal solubility, functionality, and bioavailability of bioactive compounds to be more widely used in the food field to produce safer and more nutritious food.

Author contributions

Shuangying Jia: Conceptualization; Investigation; Writing original draft, Writing – Review & Editing.

Kaichang Tan& Feng Ji: Writing – Review & Editing.

Declaration of Competing Interest

All authors declare they have no conflicts of interest for the work presented in this manuscript.