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APPLICATION AND RESEARCH PROGRESS OF MULTI-LAYER EMULSION DELIVERY SYSTEMS

Casler Buelke
Faculty of Materials Science and Engineering, Warsaw University of Technology, Poland.

Abstract: Emulsions are often used as delivery systems for active ingredients due to their unique delivery properties. Multilayer emulsions form a thicker interface layer due to their multilayer structure, thereby improving the ability of the delivery carrier to resist external pressure, prolonging the digestion time of lipids, thereby effectively protecting the active ingredients, and achieving slow release of active ingredients through the rational design of the interface layer. Purpose of ingredients. This article introduces in detail the construction principles of multi-layer emulsions, the characteristics of the interfacial layer and the effects on the stability of the interfacial layer. It also reviews the application progress of multi-layer emulsions in food and related industries in recent years, with a view to providing new methods for the delivery of active ingredients ideas.
Keywords: Emulsion; Multi-layer emulsion; Interface layer; Slow release; Application

1 STRUCTURE AND CONSTRUCTION PRINCIPLE OF MULTI-LAYER EMULSION

Active ingredients (such as curcumin, anthocyanins, tea polyphenols, etc.) have attracted much attention due to their anti-inflammatory, antioxidant, cholesterol-lowering, and lipid-lowering effects [1]. Some of them also have medical effects in preventing various chronic diseases[2]. At the same time, some active ingredients can be widely used in the food industry as natural food additives [3]. However, some active ingredients have shortcomings such as hydrophobicity, easy photolysis, and sensitivity to environmental conditions, which limit their widespread use [4]. To this end, researchers have developed various delivery systems to facilitate their widespread use and improve their bioavailability. Emulsion has become a type of delivery system that has attracted much attention from various industries due to its simple operation, green economy and other characteristics. Although single-layer emulsions are simple to prepare and can improve the bioavailability of active substances, they are still extremely unstable and prone to flocculation in the face of external environmental pressures (processing, storage, transportation, etc.) and the complex metabolic system in the body, coalescence and other physical and chemical changes [5]. In recent years, it has been found that multilayer emulsions can improve the stability of the emulsion, reduce lipid digestibility, protect active ingredients from destruction [6], and can also achieve slow release of active ingredients, greatly improving the bioavailability of active substances.

The reason why multilayer emulsion has become a hot topic in recent years is that it has a thick interface layer, which can effectively protect active substances. It can also enable active ingredients to reach the target site and achieve slow release through reasonable design. Therefore, this article introduces multi-layer emulsions from the aspects of structure and construction principles, comprehensively explains the characteristics of the emulsion interface layer and its influencing factors, and introduces the current application of multi-layer emulsions in the food industry, with a view to providing multi-layer emulsions.

Provide reference for the application of emulsions in the field of food delivery.

Multilayer emulsions are usually prepared by electrostatic deposition. Commonly used emulsification methods for preparing multilayer emulsions include high-pressure homogenization, micro-jet and ultrasonic homogenization. Oil, water and a charged emulsifier are homogenized to form a charged emulsifier coated oil-in-water or water-in-oil emulsion. This emulsion is then mixed with a solution containing oppositely charged biopolymers, which adsorb to the surface of the oil droplets and form an additional coating [7]. In this way, the multi-layer emulsion with a layer-by-layer structure forms a thick interface layer, which increases the spatial repulsion and thereby improves the stability of the emulsion. The multilayer structure can also form a stronger mechanical barrier, effectively protecting the active ingredients within the lipid droplet or polymer layer from being destroyed [8-9]. At the same time, the multilayer structure also allows controlled release in the gastrointestinal tract in vivo. Furthermore, the materials and composition of interfacial coatings can be designed as emulsions with conditioned stimulus-responsive properties to release bioactive compounds [10-11].

During the preparation process, it is usually necessary to add a washing step before each deposition. Saturation, centrifugation, filtration and other methods can be used to remove excess polymer to avoid flocculation. However, this washing step can be omitted if the biopolymer concentration is strictly controlled to ensure that the oil droplets are fully coated and no bridging flocculation occurs [12].

2 THE ROLE OF INTERFACIAL LAYER CHARACTERISTICS IN CONTROLLING THE STABILITY OF MULTILAYER EMULSIONS

In many aspects, multilayer emulsions have similar overall physical and chemical properties (rheology, optical properties, stability, etc.) as well as similar particle characteristics (concentration, particle size, net charge, etc.) to traditional emulsions[5]. The physicochemical properties of the interfacial layer (such as the thickness and structure of the layer, the interaction between adsorbed emulsifiers, the rheology of the interface, etc.) determine to a large extent the formation and stability of the emulsion [13].

2.1 Formation and Function of Interface Layer

The emulsifier unfolds or rearranges the molecular structure at the oil-water interface to form an interface layer, ensuring that the hydrophobic part is in contact with the oil phase and the hydrophilic part is in contact with the water phase. A kinetically stable emulsion can be prepared by adding surfactants (emulsifiers) to two or more immiscible phase liquids. The main function of emulsifiers is to reduce interfacial tension by adsorbing on the newly formed oil-water droplet interface. Due to their different molecular structures, the degree and rate of molecular rearrangement and adsorption of emulsifiers at the interface are also different, which ultimately affects the formation and properties of the interface layer [14]. Controlling interface features is one of the most powerful ways to design structured systems with specific functionality. For example, the characteristics of the interfacial layer, such as tension, charge, thickness, permeability, rheology and environmental responsiveness, can be controlled by selecting a specific emulsifier type, changing the system composition or processing conditions [5]. Emulsifiers with good interfacial properties should meet three basic requirements: 1) rapid adsorption at the interface; 2) ability to unfold the molecular structure at the interface; 3) formation of an interfacial film with cohesion and viscoelasticity [15]. Proteins, polysaccharides and some surfactants are often used as emulsifiers to stabilize emulsions. Proteins have amphiphilic, polymeric structure and charge characteristics, but due to their sensitivity to the environment [16], they are often combined with polysaccharides in the food industry to prepare multilayer emulsions of food-grade biopolymers.

The stability of the interfacial layer depends on the nature of the emulsifier. The reason why protein can be adsorbed at the oil-water interface as an excellent emulsifier is mainly due to polar and non-polar amino acids [17]. In addition, droplets in emulsions can be stabilized by electrostatic repulsion due to negative charges (COO-) or positive charges (NH3+) on amino acids, thereby helping to prevent aggregation of protein-coated oil droplets and control emulsion stability. The interfacial properties of protein-stabilized emulsions are also strongly dependent on the structural properties of the protein, including surface hydrophobicity and conformational flexibility [18]. If the surface hydrophobicity is too low, it is not conducive to protein adsorption on the droplet surface; if it is too high, the protein will easily aggregate and lose surface activity [14]. At the same time, adsorbed proteins with high flexibility can be easily unfolded and spread at the oil-water interface to cover the maximum surface area to form a stable emulsion [19]. The flexibility of proteins can be changed through structural modification. Li et al. [18] have shown that the combination of proteins and polysaccharides can increase the flexibility of proteins, and there is a good correlation between molecular flexibility and emulsification activity and emulsification stability.

In addition, polysaccharides or surfactant sodium lauryl sulfate (SDS) can also be used as emulsifiers to construct multi-layer emulsions, such as using amphiphilic octenylsuccinicanhydride (OSA) starch to prepare primary emulsions, and then coated with cationic chitosan to form a multi-layer emulsion [20]. There are also studies that use SDS to form an anionic surfactant-coated primary emulsion, then use the cationic polysaccharide chitosan to form a second layer, and the third layer is coated with sodium alginate/pectin to form a stable multi-layer emulsion [21-22].

In short, the type and structure of the emulsifier have a great impact on the construction of the primary emulsion. Choosing an emulsifier with high surface activity and high flexibility is conducive to the formation of a stable interface layer. Proteins are often used as the first choice of natural emulsifiers due to their amphipathic properties, high surface activity, easy modification and hypoallergenicity.

2.2 Factors Affecting the Stability of the Interface Layer

2.2.1 Thickness of interface layer

Multilayer emulsions have a thicker interfacial layer around the oil droplets. Compared with single-layer emulsion, it has better resistance to external stress, slower lipid digestion, and better biological activity protection [23]. The thickness of the interface layer is closely related to the molecular weight and structure of the emulsifier, and is also related to the conditions of the dispersed phase. For example, proteins as emulsifiers can form an interface layer 1 to 15 nm thick. This thickness is relatively thin, and the steric repulsive force formed is not enough to overcome the van der Waals attraction, so it cannot effectively suppress droplet aggregation. Therefore, the interface thickness can be increased by appropriately adjusting the hydrophilic part to effectively inhibit droplet aggregation [24]. At the same time, an interface layer that is too thick and highly charged can also lead to flocculation and coalescence by reducing the attraction and increasing the repulsion between lipid droplets. In addition, the interface thickness is greatly affected by continuous phase conditions, such as pH value, ionic strength, temperature (heating or freezing), dehydration, etc. The surface loading and thickness of the interface layer are important determinants of inhibiting Ostwald ripening of emulsions [25]. Therefore, during the preparation process, the thickness of the interface layer needs to be strictly designed to form an interface with good stability.

2.2.2 Rheology of the interface layer

The adsorption of emulsifier on the surface of oil droplets is a dynamic process. The interfacial adsorption mechanism and behavior can significantly affect the structure and mechanical properties of the interface layer. At the same time, during the emulsification process, the oil-water interface will undergo changes, such as expansion, compression (the droplet shape remains unchanged, but the size changes) and shearing (the interface area remains unchanged, but the shape changes) [14]. Therefore, rheological properties can be considered as the main properties of the dynamic characteristics of the interface. Interfacial rheology is a discipline that studies the relationship between interface stress and interface deformation. It can be divided into dilational rheology and shear rheology. The two types of rheology focus on different aspects of the interface layer. Interfacial dilatation rheology studies the relative changes between interfacial tension and interfacial area and is a very sensitive technique used to measure the adsorption and desorption kinetics of emulsifiers and explore the formation mechanism of emulsions. The dilatational rheological properties of emulsions are the most important features for analyzing the adsorption mechanism, emulsifier behavior and the thickness of the formed interfacial layer, and help predict the emulsion stability at the molecular level [26-27]. Interfacial shear rheology technology studies the relative changes between interface stress and interface shape, and can be used as a powerful tool to study the composition and interaction of adsorbed emulsifiers [28]. During shear rheology measurements, the interface area remains constant, while the in-plane shape of the planar interface changes during shear deformation, so interfacial shear rheology can provide information about the lateral cohesion of the interface layer. In summary, when measuring interfacial properties, the dominant role of the interfacial contribution of the rheological response should first be analyzed.

2.2.3 Interactions between polymer molecules

The stability of the interfacial film is controlled by a combination of electrostatic interactions, van der Waals forces, hydrophobic and hydrogen bonding interactions between polymer molecules. Therefore, improving the stability of the interfacial layer can effectively improve the physical chemistry of multilayer emulsions to a large extent. Stability and bioaccessibility of active ingredients. For example, when Leiva-Vega et al. [29] studied the complexation of phenolic acids and proteins to construct a multi-layer emulsion, they found that hydrophobic interactions were established between curcumin and coconut oil, and the assembly of gelatin and gum arabic was dominated by electrostatic interactions. The deposition of tannins is driven by hydrophobic interactions and hydrogen bonding. A stable multilayer emulsion is finally constructed through intermolecular interactions.

In summary, the stability of the interface layer is affected by many aspects, including the type, conformation, interface thickness, rheology and molecule-molecule interaction of the emulsifier. Building an interface with good stability is the key to ensuring the stability of multi-layer emulsions.

3 FACTORS AFFECTING THE STABILITY OF MULTILAYER EMULSION AND CONDITION CONTROL DURING THE PREPARATION PROCESS

3.1 Factors Affecting the Stability of Multi-Layer Emulsion

The stability of multilayer emulsions depends on the biopolymer characteristics (charge density, molecular weight and conformation, etc.), emulsifier layer thickness and bulk physical and chemical conditions at the microscopic level [30]. At the macro level, it depends on the size of the droplets in the emulsion, the concentration of the droplets or the proportion of polymers and processing parameters (such as pH value, ionic strength, dielectric constant, temperature or stirring, etc.) [16, 31]. After the emulsion is formed, because it is a thermodynamically unstable system, as time goes by, the newly formed fine droplets will decompose through various physical and chemical mechanisms such as gravity separation, droplet aggregation, and Ostwald ripening to reduce free energy.. The characteristics of the emulsifier used in the emulsion and the nature of the interfacial layer can greatly influence the above mentioned physicochemical processes. Therefore, the long-term stability of the emulsion depends on whether the structure of the emulsifier meets the requirements for generating a strong interfacial layer and the spatial location of the interfacial layer in many aspects (adsorption kinetics, surface coverage, surface charge, thickness and rheology of the interface layer) resistance and electrostatic repulsion [14].

Studies have shown that the type of polymer also affects the stability of the emulsion. Only by selecting the appropriate combination of emulsifier and polymer can the best results be achieved. At the same time, nanoemulsions (size between 20 and 200 nm) are more stable to gravity separation and particle aggregation than conventional emulsions [32]. Low concentrations of polymers are prone to flocculation and charge neutralization due to bridging, while high concentrations are prone to emulsion instability due to the depletion flocculation effect [10]. Therefore, an appropriate concentration of emulsifier helps to form a stable nanoscale primary emulsion. The type of oil also has a certain impact on the stability of the emulsion. Ozturk et al. [33] found that after digestion in the mouth and stomach, multi-layer emulsions prepared with medium-chain and long-chain triglycerides still maintain a unimodal distribution, indicating that medium- and long-chain oils The prepared multi-layer emulsion has the ability to resist droplet coalescence.

3.2 Condition Control during Preparation

The stability of multilayer emulsions depends on interfacial stability, and the stability of the interfacial layer also depends on the pH value, the initial concentration and molecular weight of the polymer [34]. The stability of multilayer emulsions containing proteins and polysaccharides changes with changes in polymer concentration [35]. The influence of pH value on the aggregation tendency of oil droplets usually depends on the change of various repulsive forces generated by the interface

layer with pH value [16], such as electrostatic repulsive force and steric repulsive force. Bassijeh et al. [36] embedded astaxanthin in a stable multi-layer solution of whey protein and Persian gum, and found that under neutral conditions, electrostatic repulsion could not mix the two polymers in a suitable ratio. When the pH value is adjusted to 4, a stable double-layer emulsion can be formed. Fioramonti et al. [37] studied that pH value and sodium alginate (SA) concentration can significantly affect the stability of flaxseed oil-in-water emulsion stabilized by whey protein isolate (WPI). The study found that the emulsion was the most stable at pH 5 and the SA mass fraction was 0.25%; ζ-potential measurements also showed that SA was deposited on the WPI interface film, forming a double-layer film around the oil droplets. Shi et al. [38] have shown that multilayer emulsions prepared from high molecular weight fucoidan have better long-term stability under high salt concentrations. In summary, to form stable multilayer emulsions at specific pH values, it is necessary to use multilayer emulsion preparation conditions that do not promote flocculation of droplets and to choose to provide strong enough electrostatic and/or steric hindrance between droplets. Repulsive polysaccharide and emulsifier combination. A summary of the condition control during the preparation process is shown in Table 1.

Table 1 Condition control during preparation

Influencing factors	Multi-layer lotion	result	references
pH value, polymer concentration	Whey protein isolate-sodium alginate	pH 4 and SA concentration of 0.125% are the optimal double-layer emulsion formation conditions.	[39]
ionic strength	Whey protein-Xanthan gum-Locust bean	At pH7, it exhibits the highest emulsion stability under the conditions of 0 and 5 mmol/L NaCl.	[40]
molecular weight	Casein-fucoidan sulfate	Multilayer emulsions prepared with high molecular weight have higher stability	[38]
Polymer type	Bovine serum albumin-chitosan-pectin	The multi-layer emulsion constructed from chitosan and pectin is more stable than other polysaccharides	[41]
Polymer concentration	Lactoferrin-alginate epsilon-polylysine	When the sodium alginate addition amount is 1%, the particle size of the secondary emulsion is the smallest and most stable.	[42]

4 STABILITY OF MULTI-LAYER EMULSION TO INTERNAL AND EXTERNAL ENVIRONMENTAL PRESSURES

4.1 External Pressure

Due to the thick interfacial layer, multi-layer emulsions have high stability to pH changes, high ionic strength, temperature and dehydration. The ability of multi-layer emulsions to resist external environmental pressure is summarized in Table 2. For example, when studying the physical stability of multilayer emulsions containing whey protein-xanthan gum-locust bean, it was found that at pH 7, the stability of the tertiary emulsions containing 0 mmol/L and 5 mmol/L NaCl was significantly significantly higher than primary or secondary emulsions, and the lipid oxidation results also indicate that multilayer emulsions have better oxidative stability [40].

Table 2 The ability of multi-layer emulsions to withstand external pressure

Multi-Layer Lotion	Active Ingredient External Pressure	Result	References
Sodium Lauryl Sulfate-Chitosan-	pH value (pH 3.0~8.0), ionic strength (≤500 mmol/L	Multi-layer emulsions perform under a wide range of external pressure conditions	[twenty two]
pectin film	NaCl), thermal processing (heating at 30~90 ℃ for 20 min) and freeze-thaw cycle (freezing at -20 ℃ for 22 h, thawing at 30 ℃ for 2 h)	Keep lotion stable	
Lupine protein isolate-chitosan-	D-limonene pH value (pH4.6), temperature (30~90℃)	Increased physical and chemical stability of multi-layer emulsions,	[43]
Pectin	NaCl concentration (0~500 mmol/L)	Can maintain better flavor	
OSA and chitosan	Beta-Carotene Acidic pH, Spray Drying	Maintain good water dispersibility and improve physical stability	[20]
Pea protein-pectin	spray drying	Improved physical stability	[30]
Whey protein isolate-sodium alginate	freeze, melt	Freeze-thaw stability of multilayer emulsions	[37]
Whey protein-Xanthan gum-Locust bean	pH value (pH7), NaCl concentration (0 mmol/L, 5 mmol/L)	The stability and oxidation stability of multi-layer emulsions are significantly improved	[40]
Lupine protein isolate-carrageenan chitosan	Astaxanthin spray drying	Multi-layer emulsions provide greater protection of active ingredients	[44]

The emulsion has better water dispersibility and beta-carotene protection. When Aoki et al. [22] studied the ability of primary, secondary, and tertiary emulsions to withstand external environmental pressure, they found that the droplets in the tertiary emulsion had different pH values (pH3.0~8.0) and NaCl concentrations (0~500 mmol/ L NaCl), heat treatment (30~90 ℃, 20 min) and freeze-thaw cycles (freezing at -20 ℃ for 22 h, thawing at 30 ℃ for 2 h, several cycles) have good stability to droplet aggregation sex. Many food emulsions undergo thermal processing such as pasteurization or cooking during production, storage or use. The use of high temperatures during the drying process of some flavored foods may also result in the loss of aroma due to volatilization [45]. In order to ensure that the emulsion will not break due to flocculation or coalescence of droplets after undergoing these heat treatments. Burgos-Díaz et al. [43] studied the retention rate of D-limonene during spray drying by different types of multilayer emulsions and evaluated its stability under different environmental stresses. It was found that three-layer emulsions stabilized by sodium alginate and pectin showed the highest flavor retention values, and two- or three-layer emulsions had the ability to withstand a variety of external stresses. The multi-layer emulsion constructed from lupine protein isolate (LPI), carrageenan (CA) and chitosan has a higher retention rate of astaxanthin than the single-layer emulsion under spray drying conditions, indicating that the multi-layer emulsion has a higher retention rate of astaxanthin under spray drying conditions. Layer emulsion has a stronger protective effect on active ingredients under spray drying conditions [43].

4.2 In Vivo and in Vitro Digestion

In the human digestive system, the digestion of emulsion mainly relies on gastric lipase and intestinal lipase. Lipase acts at the oil-water interface and reacts with lipid substrates [46]. Bile salts and phospholipids secreted in the small intestine stabilize the oil-water interface and promote lipase action. Espinosa-Sandoval et al. [47] studied the in vitro digestion experiment of a multi-layer nanoemulsion system loaded with oregano essential oil and found that 40% of the oregano essential oil in the multi-layer emulsion was available for use, while the oregano essential oil in the oil was available for use. At only 13%, the multi-layer emulsion increases the bioavailability of oregano essential oil. Abbasi et al. [48] used whey protein (WP), sodium alginate (SA) and polymer mixture (WP-SA) as encapsulation materials, and used ultrasound to assist in the formation of flaxseed multilayer nanoemulsion. In vitro digestion experiments showed that nanoemulsions stabilized by both polymers were more resistant to degradation during passage through the gastrointestinal environment. Gasa-Falcon et al. [42] developed a β-carotene-rich lactoferrin/alginate/ε-polylysine tertiary emulsion. After simulated digestion in vitro, the results showed that the tertiary emulsion was better than the first-order emulsion. and secondary emulsion had higher lipid digestibility [(83.59±11.81)%] and relatively higher β-carotene bioaccessibility [(70.10±5.26)%].

5 APPLICATION OF MULTI-LAYER EMULSION

When the active ingredients are successfully embedded in the multi-layer emulsion system, their physical and chemical stability is significantly improved, which can effectively resist complex external environmental pressures, protect the active ingredients, and sometimes slowly release the active ingredients, thereby effectively improving the biological stability of the active substances. Utilization. The application of multi-layer emulsions in improving active ingredients is shown in Table 3.

Table 3 Applications of multi-layer emulsions in improving active ingredients

Multilayer Emulsion	Oil Phase	Active Ingredient Results	References
Lactoferrin-Algin-epsilon-poly-L-lysine	Corn oil	Resveratrol increases the antioxidant properties of resveratrol	[10]
Lactoglobulin-Pectin	Corn oil	Improve chemical stability	[49]
Saponin-Chitosan-Pectin	linseed oil	Astaxanthin improves chemical stability	[50]
Lupine protein isolate-carrageenan-shell polysaccharide	Sunflower seed oil	Under spray drying conditions of astaxanthin, the retention rate of astaxanthin in multi-layer emulsions is higher than that in single-layer emulsions. liquid height	[43]
Peptide-polylysine-polyglutamic acid	soybean oil	Extend storage life	[51]
SDS-Chitosan-Alginate	Medium chain triglycerides (MCT)	Curcumin improves antioxidant capacity	[twenty one]
Whey protein isolate-chitosan-carboxymethylkonjac glucomannan	medium chain triglycerides	Curcumin bioavailability is increased by approximately 4 times, and curcumin is sustainably released	[52]
Soy lecithin-polysaccharide	vegetable oil	Stable and controlled release of volatile organic compounds over a wide range of pH, temperature and ionic strength	[53]
Lactoferrin-alginate-epsilon-polylysine	Corn oil	The physical stability and bioaccessibility of β-carotene are significantly improved	[42]
Whey protein, sodium alginate	Linseed oil	omega-3 fatty acids exhibits high tolerance	[48]

Bovine serum albumin-MCT Acacia gum	Increased physicochemical stability and controlled release of β-carotene	[54]
Whey protein-pectin-Linseed oil chitosan	Flaxseed oil is slow-release and does not reduce fat digestibility	[55]

Multiple studies have shown that two- or three-layer emulsions exhibit stronger physical and chemical stability when faced with some environmental stresses than single-layer emulsions. Guzey et al. [49] used a two-step method to prepare lactoglobulin-pectin double-layer emulsion. They added sodium chloride solution before and after pectin formation to examine the effect of ionic strength on the formation and formation of oil-in-water emulsion containing polysaccharide-protein coating droplets. impact on stability. The results show that adding salt after pectin adsorption can form stable emulsions containing polysaccharide protein-coated droplets, but adding salt before pectin adsorption cannot.

Mahmoodi et al. [46] produced a panel of probiotic yogurt using simple and multilayer emulsion encapsulated probiotics (Lactobacillus rhamnosus and Lactobacillus plantarum). During storage, probiotics encapsulated in multiple layers of emulsion have better survival capabilities, and entrapping probiotics in multiple layers of emulsion results in a more uniform structure in yogurt. Espinosa-Sandoval et al. [47] prepared a multi-layer nanoemulsion of oregano essential oil and found that its encapsulation rate in the nanoemulsion was 97.1%. Stability evaluation was conducted for 21 days at 4°C and 20°C, and the results showed that the three-layer nanoemulsion is an effective delivery system for oregano essential oil.

- carotene, Shengbrei [54] found that a double-layer emulsion prepared from bovine serum albumin and acacia gum could effectively protect β-carotene from being degraded in a simulated gastric environment and in a simulated intestinal environment. Slow release is achieved under addition, which provides an important way for the effective utilization of β-carotene in the human body. When Lin Chuanzhou [55] prepared a multi-layer emulsion of linseed oil, he found that multi-layer embedding could well retain the nutritional value of linseed oil, and the fatty acid composition of linseed oil after embedding was basically similar to that before embedding. Moreover, the oxidative stability of multi-layer emulsion is better than that of single-layer emulsion, which can slow down the change of acid value and peroxide value during storage, indicating that multi-layer emulsion has a good protective effect on linseed oil. It can effectively extend the shelf life of flaxseed oil.

In multilayer emulsions, the polymers are coated layer by layer to form a protective coating, which reduces the contact between lipase and lipids, thus delaying the lipolysis reaction [56]. Zeeb et al. [57] used structural design principles to control the rate and extent of lipid digestion in the human gastrointestinal tract, and found that the stability of emulsified oil droplets has an important impact on the rate and extent of lipid digestion. Double-layer coated lipid droplets have a stronger ability to resist lipid droplet aggregation and polysaccharide coating does not affect lipid droplet digestion. Therefore, gastrointestinal lipid digestion and slow release of active ingredients can be controlled through structural design.

Multilayer nanocomposite packaging materials can delay food spoilage by delaying food ripening, dehydration and microbial invasion, and play a great role in food preservation films. Zhang et al. [58] showed that a multi-layer active film prepared with chitosan (CS) and sodium alginate (SA) as film-forming matrix and cinnamon essential oil (CEO) as the main antibacterial ingredient can slowly release CEO, to achieve the purpose of long-term anti-corrosion and preservation. In addition, the use of multi-layer films with CEO to preserve apples can inhibit Penicillium infection for a longer period of time than single-layer films [59]. The slow release of active ingredients can effectively extend its shelf life and improve physical and chemical stability during handling and storage.

6 CONCLUSION

Multi-layer emulsions have good design and stability, which can not only effectively protect active ingredients, but also achieve slow release of active ingredients at the target site, improving the bioavailability of functional active ingredients. This article reviews the many factors that influence the stability of multilayer emulsions, the ability of multilayer emulsion delivery systems to withstand environmental stress, and the wide range of applications of multilayer emulsions in food. However, there are still some problems in the current research on multi-layer emulsions. For example, the current research on multi-layer emulsions mostly focuses on the delivery of a single active ingredient, and there is limited research on the collaborative delivery of different active ingredients; the research on multi-layer emulsions mainly focuses on multi-layer emulsions. In terms of the construction of the emulsion and the characteristics of the interface layer, the reactions that occur after the multi-layer emulsion enters the human body have not been systematically studied. Therefore, the following research can focus on the following aspects: 1) Utilize the polar characteristics of different layers of multi-layer emulsion to develop a co-delivery system of two or more active ingredients to maximize the biological efficacy of the active ingredients. 2) Develop new polymer interface layers, such as protein-polysaccharide-polyphenol modifications, to increase their antioxidant activity and improve their functions. 3) Conduct systematic research on it and toxicological exploration of human body functions. It is expected that more research will be invested in the molecular level of multi-layer emulsions and the metabolic transformation in complex human systems, so as to realize large-scale production from laboratories to enterprises as soon as possible.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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