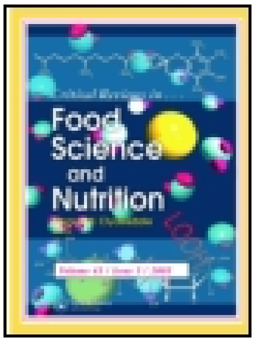

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Application of edible coating with essential oil in food preservation

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Abstract

Compared with other types of packaging, edible coatings are becoming more and more popular because of their more environmentally friendly properties and active ingredients carrying ability.

The edible coating can reduce the influence of essential oils (EOs) on the flavor of the product and also can prolong the action time of EOs through the slow-release effect, which effectively promote the application of EOs in food. Understanding the different combinations of edible coatings and EOs as well as their antimicrobial effects on

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different microorganisms will be more powerful and targeted to promote the application of EOs in real food systems.

The review focus on the contribution of the combination of EOs and edible coatings (EO-edible coatings) to prolong the shelf life of food products, (1) specifically addressing the main materials used in the preparation of EO-edible coatings and the application of EO-edible coatings in the product, (2) systematically summarizing the main production method of EO-edible coatings, (3) discussing the antiseptic activity of EO-edible coatings on different microorganisms in food.

Keywords: Edible coating; Essential oil; Preservation; Antimicrobials; Fabrication; Mechanisms

Introduction

In the past few years, due to the rejection of the sulfite, synthetic additive benzoic acid or its derivative salt usually used to control the growth of the microorganism in food by general consumer, natural antimicrobial agents used in food preservation has attracted more and more attention (Ju et al., 2017). In order to improve the quality and safety of products, while maintaining their good nutritional and sensory properties, food authorities and researchers have assessed the feasibility of using mild preservation techniques in detail (Ju et al., 2018; Goni et al., 2009). Nowadays, natural biological preservatives are considered to be safety. Natural biological preservatives are mainly extracted from edible spices, and the EOs from these spices have been found to be effective preservatives (Ju et al., 2018; Ishlak et al., 2015; Kim and Rhee, 2016; Matan

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et al., 2006). EOs are the secondary metabolite of aromatic plants, which has a wide range of biological activity (Abd-Elsalam and Khokhlov, 2015). So far, EOs has been developed as an additive for many products, such as food, drugs and cosmetics. Since EOs are the secondary metabolites of plants, they are generally considered to be safe products. According to FDA (American food and Drug Administration) (Administration, 2014), EOs are generally recognized as safe (GRAS), which can be used as a potential substitute of synthetic additives (Ju et al., 2018; Atarés and Chiralt, 2016; Ruiz-Navajas et al., 2013).

However, EOs usually has a strong lipophilic and volatile and are almost insoluble in water. It's a complex mixture, the components of which can be divided into alkaloids, flavonoids, isoflavones, terpenoid, phenolic acids, carotenoids and aldehydes (Bakkali et al., 2018; Seow et al., 2014). Because of the instability and lipophilic, there are only 300 kinds EOs used in business in 3000 kinds of known EOs, currently (Dima and Dima, 2015).

Moreover, it is a powerful challenge for EOs to be blended into food and beverage products directly because of its instability and hydrophobicity. Therefore, in order to maintain the biological activity, increase the effective utilization rate and minimize the impact on food organoleptic properties of EOs, they need to be encapsulated in a conveying system compatible with food applications (Buranasuksombat et al., 2011). This can effectively avoid the instability of EOs and increase their contact area with food, besides, it can be easily dispersed in those areas where microorganisms grow and proliferate (Donsì et al., 2011).

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The edible coating is defined as the thin layer of edible material, which is applied on food surface in liquid form. Some of its basic functions are to protect the product from mechanical damage and chemical reaction as moisture barrier (Embuscado and Huber, 2009; Miller and Krochta, 1997). Here it is worth to mention that coatings should not be confused with films as the two are altogether different. Biofilms are generally produced from edible and renewable resources, and in most cases they are easier to degrade than polymeric materials. The edible films are first formed as thin solid layer or sheets, which are then applied as a wrapping on the food product whereas, the edible coatings are applied in liquid form on the food to be coated, usually by immersing the product in a solution of structural matrix forming substances such as carbohydrate, protein, lipid or mixture of these (Galus and Kadzińska, 2015). The increased interest in edible coating has been motivated by increasing consumer demand for safe, convenient, and stable foods, and the awareness of the negative environmental effects of non-biodegradable packaging.

Edible coatings have high potential for carrying active ingredients, such as antimicrobial agents, anti-browning agents, colorants, as well as spices and nutrients. EO-edible coatings are conducive to the use of EOs in foods by increasing their distribution in the food areas where microorganisms grow and proliferate, as well as by enhancing their antimicrobial activity. Therefore, the EO-edible coatings are considered as an effective and innovative method in keeping food quality. Moreover, EO-edible coatings also provide additional advantages, such as minimize the impact on the sensory characteristics of foods, as well as the increase of the biological active

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substances (Donsì et al., 2011; Donsì et al., 2012a). Although the permeability and mechanical properties of EO-edible coatings are generally worse than those of synthetic membranes, which will limit their application in particular foods, but these limitations will be overcome with further research.

This review will discuss the effective contribution of the combination of natural preservatives (EOs) and edible coatings to food, and also paid special attention to the species and preparation systems of EO-edible coatings of, besides the antimicrobial activity data and antibacterial mechanism of EO-edible coatings were analyzed systematically.

Materials used for EO-edible coatings

Edible coating is a new packaging strategy to extend the shelf life of food. Edible coatings obtained from natural resources are not only environmentally friendly, but also able to maintain the quality of food and extend the shelf life of food. In the past, the edible coating materials have been investigated by many researchers. And with the growing demand for environmentally friendly and healthy products, more and more attention has been paid to edible coatings. So far, a variety of functional edible coatings have been developed rapidly, but according to our investigation and analysis, the EO-edible coatings were found to have attracted more attention of researchers. Fig.1 compares the quantity of published literature on EOs as antimicrobial agents, edible coatings and EO-edible coatings over the last 10 years. It can be seen from Fig.1 that EOs as antimicrobial agents and studies on edible coatings are considered to be in

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exponential grow. These date indicate that the study of edible coatings and EOs as antimicrobial agents has almost reached maturity. However, according to our investigation, it is found that the research on EO-edible coatings is still at a stage of development, and about 400 publications are published every year in recent two years.

Coatings can be formulated from different materials and have desired properties. The basic materials for the production of EO-edible coatings are mainly divided into three categories, polysaccharides, proteins, and **lipids**. (Donhowe and Fennema, 1993; Pan et al., 2013) (Table.1). EO-edible coatings made of different polysaccharides, proteins and lipids are conducive to reduce the oxidative degradation of foods, inhibit the growth of spoilage microorganisms and prolong the shelf life of food. Therefore, the development of EO-edible coatings has attracted considerable attention in recent years. Fig.2 Potential food to be considered for coatings applications.

Polysaccharide based coatings

In recent years, there are many literatures about polysaccharide edible coatings applied in products. Due to hydrophilic nature, polysaccharide based coatings may provide only a minimal moisture barrier (Dehghani et al., 2018). Although polysaccharide coatings may not provide a good water vapor barrier, Kester and Fennema (1986) reported that these coatings can act as ‘‘sacrificing agents” retarding moisture loss from the food products by adding additional moisture on the surface that is lost first. At the same time, after the combination of polysaccharide coating and functional EOs, the conjugate has strong antibacterial and antioxidant effect, which is

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better able to maintain the original quality and prolong the shelf life of food. The polysaccharide coating mainly includes natural gum, chitosan, starch, alginate, carrageenan and gellan gum etc. Hamedi et al., (2017) had researched the effect of alginate coating combined with Ziziphora EO on the quality of the chicken slices during refrigerated storage and found that the coating could restrain the growth and reproduction of *E. coli*, *P. aeruginosa* and monocytic lester significantly ($P < 0.05$) during storage and also could reduce the formation of peroxide. Perdones et al., (2016) combined pure chitosan coating with lemon EO for strawberry preservation, and found that chitosan coating can promote the formation of ester in a very short time and besides, the conjugate can transfer the terpene volatiles to the fruit, which made the original fruit flavor more obvious. In the early years, Azarakhsh et al., (2014) optimized the mixture ratio of alginate and gellan gum to research its effect on the quality of fresh pineapple.

Natural rubber obtained from various plant species has been proved to be effective natural paint. These types of natural rubber mainly from plantain seed (Behbahani et al., 2017), perilla seed (Hashemi et al., 2017), psyllium husk (Yousuf and Srivastava, 2015), aloe vera (Benitez et al., 2013) and locust bean (Perez-Gago et al., 2005). The plantago asiatica seed gum and chitosan coating were used in the preservation of fresh cut apples, respectively. The results showed that the seed coating of plantago asiatica could keep the color of fresh cut apples or prevent enzymatic browning compared with chitosan coating (Banasaz et al., 2013). There are also studies which used aloe vera gel, shellac and lemon EO as coating to maintain the quality of apple slices. The results

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showed that coating can effectively reduce the synthesis rate of ethylene during storage and also can restrain the oxidase activity and maintain the original color of apple (Chauhan et al., 2011). In addition, some researchers developed and optimized the sophora bean gum edible coatings which were future used to prolong the shelf life of 'Fortune' mandarins (Rojas-Argudo et al., 2009).

Chitosan obtained by deacetylation of chitin, also called deacetylation chitin, is a safe, non-toxic and biodegradable natural polysaccharide. It has been proved to be an effective natural antibacterial substance and its antibacterial activity is considered to be one of the most interesting characteristics of Chitosan. Many studies reported the application of chitosan in food. Guerra et al., (2016) studied the effect of chitosan coated with peppermint EO on the quality of fresh grapes. The results showed that the coating can significantly ($P< 0.05$) inhibit the fungal infection in grape during storage. Azevedo et al., (2014) also explored the effects of edible coating formed by chitosan and carvacrol on postharvest quality of strawberries. The results showed that the coating could effectively inhibit the decay rate of strawberry during storage. In addition, a number of researchers have used chitosan coatings for the preservation of mangoes, grapes and guavas (Oh et al., 2017; Frazão et al., 2017; de Aquino et al., 2015).

At present, many native and modified starches from plants have been used in the formulation of edible coatings. Related research used the edible coating of natural or modified corn and cassava starch for the protection of carotene in pumpkin during drying and the result showed that the coating has a significant ($P< 0.05$) inhibit effect

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on the degradation of carotenoids in pumpkin (Tavassoli-Kafrani et al., 2016). Alotaibi et al., (2017) studied the effects of sweet potato starch combined with thyme flavor coating on the quality of shrimp during freezing. The result showed that the coated shrimp still had higher sensory acceptability and lower colony total value at the end of storage.

Pectin is the soluble component of plant fiber derived from plant cell wall. These polysaccharide derived from plant has poor water holding capacity, so they seem to have a good match with low moisture foods. Gharibzahedi and Mohammadnabi (2017) used the mixture coating of jujube gum and nettle EO to extend the shelf life of sturgeon fillets. Guerreiro et al., (2015) studied the effect of pectin and citral composite coating on the quality of fresh raspberries. Martinon et al., (2014) used pectin and other materials to develop a multilayer coating system to extend the shelf life of freshly cut cantaloupe.

Protein based coatings

It has been found that proteins derived from corn, wheat, soybeans, peanuts, milk or gelatin are suitable for the coating of many foods. Most EO-edible coatings based on protein show good hydrophilic, but in most cases they exhibit poor water vapor diffusivity.

Gluten, collagen, zein, casein and whey proteins all can be used for the preparation of EO-edible coatings. Moradi et al., (2016) studied the inhibitory effects of Zataria multiflora Boiss EO combined with edible coating based on corn protein on the *L.*

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monocytogenes and *E.coli* in beef. The results showed that this edible coating could inhibit the growth and reproduction of *L. monocytogenes* and *E.coli* significantly ($P < 0.05$) during the storage of beef and also showed that *L. monocytogenes* was more sensitive than *E.coli* to the coating. Catarino et al., (2017) developed a new edible coating of EO by combining whey protein with oregano EO, which was successfully applied in the processing of meat products. Prior to this, Correa-Betanzo et al., (2011) treated cactus with edible coating based on sodium caseinate and then evaluated its effects on the chemical composition of cactus. It was found that the coating can help to retain the chemical composition of the plant, but the authors proposed the composite coating be used to prevent the rapid deterioration of cactus structure. Recently related research found that edible coating containing cinnamon EO can significantly ($P < 0.05$) reduce the oxidation of ham and inhibit the growth of microorganisms during storage (Dai et al., 2017). In addition, there was related scholar had explored the effect of the combination of peanut protein, chitosan and cinnamon EO on the shelf life of fish. The results showed that this method can significantly ($P < 0.05$) inhibit fish spoilage (Li et al., 2014).

Lipid based coatings

The lipid coating is usually made up of wax, acyl glycerol or fatty acids. This kind of hydrophobic edible coating not only can help to reduce the effects of water, light, oxygen and other external factors on food quality during storage, but also can reduce the water evaporation rate of food itself. In the early days, researchers have explored the inhibitory effect of lipid coating containing oregano EO on *L. monocytogenes*, and

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the result showed that the EO encapsulated by liposomes had stronger antimicrobial activity than the unsealed EO (Liolios et al., 2009). And some other researchers also found that the lipid coating containing lemon EO and rosemary EO has good preservation effect on spinach (Alikhani-Koupaei, 2014). However, according to investigation, there is relatively little research on the lipid coating containing EOs, and the research on the composite coatings containing EOs has gained more attention.

Composite coatings

Composite coating mainly refers to the combination of water colloids (proteins or polysaccharides) and lipids (Yousuf et al., 2017). The coating prepared by single material can exhibit good correlation, but it may not provide multiple functions. For example, polysaccharides and proteins are good film forming materials which can provide excellent mechanical and structural properties, but their moisture proof effect is poor. Fortunately, the use of hydrophobic lipid components can compensate the drawback. That is to say the composite coating combines the advantages of single coating and avoids its disadvantages at the same time. Therefore, the development of composite coating has gained more attention at present. Azarakhsh et al., (2014) evaluated the effects of composite coatings (glycerol, sodium alginate and lemon EO) on respiration rate, physicochemical properties, microbial and sensory quality of fresh pineapple and the result showed that the coating could significantly ($P< 0.05$) prolong the shelf life of fresh pineapple. Chiumarelli et al., (2014) investigated the effect of the composite edible coating composed of cassava starch, glycerol, brazil palm wax and stearic acid on the quality of apple slices. The results showed that the coatings exhibited

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the best preservation performance when their mass ratios were 3%, 1.5%, 0.2% and 0.8%, respectively. Fan et al., (2009) prepared a composite coating containing fish gelatin, chitosan and oregano EO by solvent casting method and composite coating had proved to have a good inhibitory effect on *S.aureus* and *L. monocytogenes*. In addition, the related researchers explored the effect of the thyme EO combined with composite packaging on the shelf life of fresh cut lettuce (Deng et al., 2016). Other researchers have explored the compound coating of whey protein concentrate or hydroxypropyl methylcellulose as hydrophilic phase, beeswax or carnauba wax as a lipid phase. The results showed that the composite coating of whey protein and beeswax could delay the enzymatic browning reaction of apple slices (Perez-Gago et al., 2005).

Definition and production method of coating

Definition of EO-edible coating

EOs-edible coating is a layer of paint the mixture of EOs and biological polymers which are able to carry oil (protein, natural gum, modified starch and lipids, etc.). It can not only prevent the exchange of oxygen, water and carbon dioxide from external and other substances with food, but also can delay the deterioration of food, so as to play a role in preservation. When eaten, they can be eaten together with food, but also can be washed away. Fig.3 introduces the production method of the EOs-edible coating and the application process in the food.

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Production method of coating

The preparation methods of EOs-edible coating mainly include spraying method, dipping method, spreading method and thin film hydration method. The manufacturing methods and details of EOs edible coating are given in Table. 2.

Dipping method

Among the whole methods, only dipping technique can form high thickness coatings (Dhanapal et al., 2012). Dipping method is mainly used for fruit, vegetable and meat products (Tavassoli-Kafrani et al., 2016). The density, viscosity and surface tension of the coating solution have an important influence on the properties of the coating. In dipping method, the food is directly immersed in the corresponding coating solution and removed after a certain period of time. After natural drying, a thin coating layer is formed on the surface of the product. Another method is named as foam application method. This method is usually prepared in emulsion. In this method, the foam will break down by repeated rolling action, so the uniform distribution of coating solution will be over the surface of the product (Tharanathan, 2003). Hamzah et al., (2013) had prepared the coating by dipping method and then studied its effect on the texture and color of papaya. The sodium hydroxide and sodium alginate composite coatings were also prepared by this method, and the effect of the coating on the shelf life of fresh carrots was studied (Mastromatteo et al., 2012). The results showed that this coating could prolong the shelf life of carrots by 7 d. However, it is difficult to form a good attachment to fresh cut fruits. Therefore, there are some limitations in the formation of

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edible coatings on micro machined fruits. At present, multilayer technique is developed to overcome this defect. Here, two or more layers of material are combined with each other by physical or chemical means (Skurtys et al., 2010). For example, Sipahi et al., (2013) explored the effect of the composite coatings of multilayer antimicrobial algal base and cinnamon EO on the shelf life of fresh watermelon. The results showed that this composite coating can keep the quality and sensory of fresh watermelon and also can prolong its shelf life.

Spraying method

Spraying method is suitable for low viscosity solution, which can be easily sprayed under high pressure (60-80psi) (Dhanapal et al., 2012). The droplet diameter of the solution formed by this method can reach about 20 microns. For example, Xu et al., (2016) prepared a perilla seed EO edible coating successfully by spraying method. The droplet formed by this method has homogeneous and beautiful appearance. However, the polymer coatings formed by spray systems may be affected by other factors, such as drying time, drying temperature and drying method, etc. (Skurtys et al., 2010).

Spreading method

Spreading method that the coating solution spread directly on the product is a kind of method which is affected by human factors seriously. Ju et al., (2018) used cinnamon and clove EO coating for the preservation of baking by this method. The result showed that this method can significantly ($P< 0.05$) prolong the shelf life of baked foods and also had no significant ($P > 0.05$) influence on the sensory quality of baked foods. Gonz

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ález-Forte et al., (2014) also brushed two different coatings on pet biscuits using this method. The alginate solution was first brushed onto the surface of the biscuit and then the $CaCl_2$ solution was sprayed to form the gel. Finally, the suspension obtained from gelatinized corn starch was sprinkled on the cookie.

Thin film hydration method

Film hydration method is mainly to dissolve phospholipid, cholesterol and other membrane forming substances in organic solvents, and then remove organic solvents with rotary evaporator, add appropriate buffer, and fully hydrate and disperse finally (Gortzi et al., 2006). In order to reduce the particle size of liposomes and increase the uniformity of liposome size, the products produced by this method need to pass the filter membrane with certain pore size under certain pressure. This method is the most primitive and the most basic method. It is not only easy to operate but also has high encapsulation efficiency. In the past few years, some researchers used this method to explore the effect of liposome embedded lemon EO (EO-liposomes) on spinach quality. The results showed that the EO-liposomes prepared by this method could maintain spinach quality better (Alikhani-Koupaei, M. 2014). However, due to the limitation of film-forming area, the output of the products produced by this method is small and the continuity is poor, so it is not suitable for large-scale industrial production.

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Antibacterial activity of EO-edible coating

In recent years, the demand for natural, friendly and safe derivatives to replace synthetic food additives is becoming more and more intense. Hence, EOs are widely recognized as an antiseptic (Seow et al., 2014). Although it had been determined that the antimicrobial activity of EOs mainly depended on multiple targets in the cell but not a specific mechanism, their antimicrobial effect mainly based on their molecular hydrophobicity in the final analysis (Salvia-Trujillo et al., 2015a). Phenolic compounds in EOs have strong interaction with lipids in cell membranes, thus increasing the permeability of cell membrane, disrupting or destroying the cellular structure and causing the leakage of intracellular material (Seow et al., 2014). Formulation of EO-edible coatings tested against different microbial species and strains.

At present, there have been a lot of studies on the inhibitory effects of edible coatings against different microbial species and strains from different foods. Table.3 shows the main researches on EO-edible coatings and also summarized the mechanism of microbial species, antibacterial materials and mechanism action of EO-edible coatings. In the past decades, the inhibition of EOs on food spoilage and pathogenic bacteria has been extensively studied. According to related reports, gram positive bacteria are considered to be more sensitive to EOs than gram negative bacteria, which possibly because of their different cell wall structures (Seow et al., 2014). The gram positive bacteria has a thick cell wall, the average thickness of which is about 20~80

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mm. Besides, it has a rich content of peptidoglycan, which occupies 50% to 80% dry weight of the cell wall. In addition, it contains a large number of special components, such as phosphoric acid. However, the thickness of the cell wall of Gram-negative bacteria is about 10~15 nm (Wu et al., 2014). Therefore, hydrophobic molecules can easily penetrate the cell wall of gram negative bacteria, which is different from gram positive bacteria, the outer membrane of which is almost impermeable (Nazzaro et al., 2013).

In general, the antimicrobial efficacy of edible coatings mainly depends on the constituents of EOs. Table.3 shows that in recent years there have been a large number of researches on different gram positive bacteria, such as *S.aureus*, *S.hemolyc* and *L. monocytogenes* and different gram negative bacteria, such as *E.coli*, *S.enteritidis* and *S.typhimurium.* In addition, some studies have also solved the effect of edible coating of EOs on yeast cells. Yousuf et al., (2017) pointed out that the lemongrass EO-edible coating could effectively inhibit the growth of yeast. Artiga-Artigas et al., (2017) studied the effect of the oregano EO-edible coating on the shelf life of the cheese. And the result showed that the coating could effectively inhibit the growth of the yeast in the storage of cheese. Frazão et al., (2017) also studied the effects of Myrcia ovata Cambessedes EO-edible coatings on the quality of mangaba fruits storage. The result showed that this method could effectively control the growth and reproduction of yeast and mould of mangaba fruits during storage. According to relevant studies, many EO-edible coatings have been found to have stronger antimicrobial activity and longer duration than free EOs. This may be because the formulation and surface charge of

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edible coatings affect the mechanism of EOs to the cell membrane. Even in many cases, EO-edible coating can interact with multiple molecular sites on microbial cell membrane. According to relevant literature, the use of large molecules may help to improve the anti-microbial activity of EOs. For example both the combination of sodium caseinate and thyme EO (Xue et al., 2015), or the combination of sodium alginate and citronella EO can play a synergistic inhibitory (Salvia-Trujillo et al., 2015a; Salvia-Trujillo et al., 2014a). Interestingly, however, it is reported that the interaction of some macromolecules as emulsifiers and EO can reduce the antimicrobial activity of EO to a certain extent. For example, the coating of whey protein and maltose dextrin combined with lilac EO shows lower antimicrobial activity than free EO. The reason for this phenomenon may be that some polymer matrices are made into EO-edible coatings after the interaction with EOs, which can produce electrostatic interactions with corresponding cell membranes. Or because the proportion of the water phase contained in the coating is large, which greatly reduces the interaction between the EO and the cell membrane. The different interpretations proposed above are illustrated in Fig.4.

The interaction between EO-edible coating and the membrane of the microorganism may be promoted mainly through the following ways. First of all, the interaction of EO-edible coating with cell membrane can be improved by increasing the contact area between EO and cell membrane (Donsì et al., 2012a). In addition, EO can also destroy the cell membrane by altering the integrity of the phospholipid bimolecular layer or by inhibiting the active transporter protein (Moghimi et al., 2016). Secondly, the edible

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coating with emulsification can fuse with the phospholipid bilayer of cell membrane, which may promote the targeted release of EO on cell site. In addition, the specific interaction between the emulsifier and the cell membrane has been reported to be able to increase the antibacterial activity of EO (Salvia-Trujillo et al., 2015a; Salvia-Trujillo et al., 2014a). Third, the edible coating with positive charge can interact with negatively charged microorganism cell walls, which can increase the concentration of EO (Chang et al., 2015). However, this hypothesis is still controversial. For example, cationic surfactant such as lauric acid also has strong antimicrobial activity (Xue et al., 2015; Chang et al., 2015). And it is also reported that the charge of the emulsion does not affect the anti-microbial activity of the EO (Majeed et al., 2016b). Finally, the edible coating may delay the release of the EO components and prolong the action time of it. In accordance with this hypothesis, related research had found that the EO-edible coating could significantly ($P< 0.05$) prolong the action time compared with free EO (Xue et al., 2015; Salvia-Trujillo et al., 2014a). The mechanisms of the different routes described in Fig. 4 may coexist and are difficult to appear alone. Therefore, further explorations are needed to improve the understanding of the basic mechanism of EO-edible coating, so as to improve the specific antibacterial effect of antibacterial agents on target microorganisms.

Conclusion and outlook

Consumers' demands for safe, friendly, natural in past few years have promoted the development of mild preservation technology, which will improve the quality and safety of the product without causing the loss of nutritional and sensory. Although

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natural antimicrobial agents (such as EOs) have the potential to keep quality and safety benefits, their application in food is limited because of the inherent volatility and special odor (Lucera et al., 2012). With the development of technology, the researchers found that the defect could be solved by adding EOs to the edible coating. EOs encapsulated in edible coating have better physical and chemical stability, which shows more fresh-keeping advantage for food.

However, several challenges still remain for the full exploitation of EO-edible coating within a mild strategy for food preservation. As mentioned earlier, some researchers have found that the interaction of some individual macromolecules used as emulsifiers with EO can reduce the antimicrobial activity of EO to some extent. Therefore, finding a proper combination of food and coating materials is an important factor to be considered. In addition, an important role of the EO-edible coating is the controlled release of EOs. In this respect, it will be a great value to combine it with food packaging materials in the packaging industry. But how to solve the activity of EOs during the high temperature production of packaging materials will be an important problem. And we also should establish a relationship between the prescription of the EO-edible coating and the species that it inhibits, so as to select the optimum EO-edible coating based on different spoilage microbes. In this way, it can play a better role in its antimicrobial activities. In addition, EOs usually have larger pungent odors. If they are applied directly to the food surface, they will have a certain effect on the quality of food finally. Therefore, it is also the focus of our future research on how to cover the odor of

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EO under the premise of guaranteeing the antibacterial activity of EO and the slow release effect of the coating (Severino et al., 2015).

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Conflict of interest

The authors declare no competing interests

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Table and Figure captions

Table.1 The basic materials for the production of EO-edible coatings and applications in food.

Coating types	Essential oils	Functions/Results	Product application	References
Polysaccharides				
Alginate and gellan based edible coatings	Cinnamon essential oil and rosemary essential oil	As an excellent carrier of essential oils; Adding cinnamon oil and rosemary oil is more effective than using alginate alone.	Fresh-cut apple	Rojas-Grau et al., 2009; Chiabrando and Giacalone, 2015
Alginate and galbanum gum based edible coatings	Ziziphora persica essential oil	Edible coating has obvious antibacterial and antioxidant activity, significantly improve the shelf life of chicken.	Chicken fillet	Hamedi, Hassan, et al. 2017
Alginate and carrageenans based edible coatings	Lemongras s essential oil	This coating has the reproducibility and degradability was very suitable for food packaging; can prevent food spoilage and microbial contamination, better maintain the sensory attributes of food.	Papaya Fresh-cut pineapple	Hamzah et al. 2013 Azarakhsh et al. 2014
Alginate-based coating	Cinnamon, palmarosa or Lemongras	The coating improves the shelf life of fruits and vegetables and meat products from	Fresh-cut melon Poached and deli	Raybaudi-Massilia, Mosqueda-Melgar, and Martin-Belloso,

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	s essential oil	the viewpoint of physical chemistry and microbiology.	turkey products	2008 Juck et al. 2010
Jujube gum	Nettle essential oil	The coating improves the shelf life of Beluga sturgeon fillets from sensory, microbiological and physicochemical perspectives.	Beluga sturgeon fillets	Gharibzahedi,S.M.T., and Mohammadnabi, S. 2017
Flaxseed gum	Lemongrass essential oil	During the 12 days of storage in the coating effectively inhibited the growth of yeasts and molds, reduce the color change of the samples.	Pomegranate arils	Yousuf, B., and Srivastava, A. K. 2017
Basil seed gum	Thymol and viride essential oils	The coating significantly reduced the increase of PV and TBA value during frying, and obtained better taste and appearance.	Shrimp; fresh cut apricots	Khazaei, N., Esmaiili, M., and Emam-Djomeh, Z. 2016; Hashemi, et al. 2017
Plantago major seed mucilage	Anethum graveolens essential oil	Compared with the control group, the experimental group prolonged the shelf life of beef 9 d.	Beef	Behbahani, et al. 2017
Chitosan coating	Mentha, oregano and lemon essential oils	The coating significantly inhibited the fungal infection of grape during storage, and maintained the original quality better. The coating effectively	Grape; ready-to-eat barbecued chicken;	Guerra, et al. 2016; Firouzi, et al. 2007; Perdones, et al. 2012

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		inhibited the growth of Listeria monocytogenes and Yersinia enterocolitica during storage of barbecued chicken. The coating inhibits the incidence of gray mold disease during storage of the strawberry.	strawberry	
Hydroxypropyl methylcellulose	Oregano and bergamot essential oils	The 'Formosa' plum in the experimental group had better appearance and quality.	'Formosa' plum	Choi et al. 2016
Starch-based coating	Nigella sativa oil	The coating treatment significantly reduces the softening rate of pomegranate, reducing the loss of vitamins and anthocyanins.	Pomegranate arils;	Oz and Ulukanli 2012
A sweet potato starch-based coating	Thyme essential oil	Edible coatings effectively extend the shelf life of shrimp during chilling.	Shrimp meat	Alotaibi, S., and Tahergorabi, R. 2017
Tapioca Starch and decolorized Hsian-tsao Leaf Gum	Cinnamon essential oil	Coating can effectively delay the browning of fresh-cut apples.	Apple	Pan et al., 2013
Proteins				
Whey protein	Origanum virens essential oils	The coating effectively inhibited the growth and reproduction of microorganisms,	Sausages	Catarino et al., 2017

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		inhibited the evaporation of water, and prolonged the shelf life of sausage by about 20 d		
Zein	Zataria multiflora Boiss. essential oil	The Lester bacteria in beef were significantly inhibited when the coating was used.	Beef	Moradi et al., 2016
Soy protein	Cinnamon and clove essential oils	The water loss rate and total bacterial count of pork decreased significantly during cold storage, which significantly improved the shelf life of pork.	Pork	Zhang et al., 2012
Peanut protein	Cinnamon essential oil	The coating has a good inhibitory effect on Escherichia coli, Staphylococcus aureus and Pseudomonas fluorescens.	Fish	Li et al., 2014
Lipids				
Phosphatidylcholine and cholesterol	Lemon and rosemary essential oils	The method can effectively inhibit the activity of peroxidase and polyphenol oxidase in spinach, and has great potential for prolonging the shelf life of vegetables.	Spinach	Alikhani-Koupaei 2014
Phosphatidylcholine	Oregano essential	Encapsulation of essential oil with	-	Liolios et al., 2009

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	oil	liposome can enhance the antibacterial activity of free essential oil		
Composite coatings				
Pectin-and alginate-based edible coatings	Iemon essential oil	The results show that the composite coating can significantly reduce the raspberry color and weight reduction during storage, reducing the growth of spoilage microorganisms.	Raspberries	Guerreiro et al., 2015
Gelatin and chitosan containing	Origanum vulgare L. essential oil	The composite coating has obvious inhibitory effect on Staphylococcus aureus and Listeriamonocytogenes.	Sweet potato	Hosseini et al., 2015
Lard and starch edible coatings	Litsea cubeba and cinnamon essential oil	The results showed that antimicrobial and antioxidant coating can effectively reduce lipid oxidation and inhibit the growth of microorganisms in semimembranosus in dry-cured ham.	Dry-cured ham	Dai et al., 2017
Sodium bicarbonate and	Innamon	The results show that a certain concentration	Cherry and	

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rhamnolipid	essential oil	of sodium bicarbonate can effectively reduce the use of laurin oil, and laurin essential oil has some synergies.	tomato	Xu., 2016
Shrimp chitosan and the essential oil from Mentha piperita L. (MPEO) or M. villosa Huds (MVEO)	Mentha piperita L or M. villosa Huds essential oil	The coating can effectively inhibit the pollution and growth of plant pathogenic fungi.	Grape	Guerra et al., 2016

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Table.2 The manufacturing methods and details of EO-edible coatings .

Method	Preparation conditions	Influencing factors	Product properties	Advantages and disadvantages	References
Dipping method	Medium viscosity coating solution	Solution density, viscosity and surface tension, etc..	The coating is thick and uniform	Advantages：Easy to operate, do not require high technical means and equipment. Disadvantages：Does not apply to the appearance of the higher requirements of the product	Dhanapal et al, 2012
Spraying method	Low viscosity coating solution	Drying time, temperature and experimental methods, etc..	The coating is thin and uniform	Advantages：It has good product performance and satisfactory appearance. Disadvantages：Not suitable for high viscosity solution, the equipment and technical requirements are relatively high.	Xu et al. 2013
Spreading method	High viscosity coating solution	Affected by human factors	Coating thickness between the above two methods, a little uniform	Advantages：Flexible and convenient; suitable for high viscosity solution. Disadvantages：Affected by human factors (non-uniform coating)	Ju et al. 2018
				Advantages：The operation is simple and	

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Thin film hydration method	Organic solvent	Rotary evaporation time	Poor uniformity of liposome particle size	the encapsulation rate is high. Disadvantages：Due to the limitation of film-forming area, the output of the products produced by this method is small and the continuity is poor, so it is not suitable for large-scale industrial production.	Gortzi et al. 2006

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Table.3 Formulation of EO-edible coatings tested against different microbial species and strains.

Classification	Microorganism	Coating composition	Product	Result	Antibacterial mechanism	References
Gram+bacteria	Listeria monocytogenes	Whey protein, origanum virens essential oil	Sausages	Coating inhibited the growth of Listeria monocytogenes and delayed the lipid oxidation of sausage during storage	Eo coating prolongs the antibacterial activity of Eo by sustained release; Coating improves the solubility of EO.	Catarino, M. D., 2017
		Sodium alginate-carboxy methy lcellulose and *Ziziphora clinopodioides* essential oil	Silver carp fillet	This method significantly inhibits the growth and reproduction of Listeria monocytogenes during storage	The combination of EO and coating increases the ability of EO to enter the cell and increases the antibacterial activity of EO.	Rezaei, F., and Shahbazi, Y. 2018
		sodium alginate, galbanum gum	Chicken	EO coating significantl	Coating prolongs	

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	and *Ziziphora persica* essential oil	fillet	y inhibited the growth and reproduction of microorganisms in chicken fillets during late storage.	the antimicrobial activity of the essential oil	Hamedi, H., 2017
	turmeric residue, gelatin hydrogelor cassava starch, gelatin hydrogels and purified curcumin	Sausages	The coating has a great antibacterial potential for sausages.	The combination of the coating with EO enhances the antibacterial activity of EO.	Tosati, J. V., 2018
	Chitosan-cassava starch, *Lippia gracilis* essential oil	Guavas	Good to keep the quality of guavas during storage	Coating improves EO dispersibility.	de Aquino, A. B., 2015
Staphylococcus aureus	Carboxymethyl cellulose and garlic essential oil	Strawberries	The coating for food preservation has greater potential applications.	The coating improves the solubility of the EO and enhances the ability of the EO	Dong, F., and Wang, X. 2017

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				to enter the cell.	
	Sodium alginate, mandarin fiber, Tween 80 and oregano essential oil	Low-fat cut cheese	Edible coating can better inhibit the growth of microorganisms, so that the appearance and nutrition of cheese has been better maintained.	Coatings improve the dispersion of EO and prolong its effective antimicrobial time.	Artiga-Artigas, M., 2017
Bacillus subtilis	Chitosan-cassava starch, *Lippia gracilis* essential oil	Guavas	Good to keep the quality of guavas during storage	The combination of coating and EO increases the antibacterial activity of EO.	de Aquino, A. B., 2015
	Cassava starch, chitosan, thymol and carvacrol	Strawberries	Edible coating effectively inhibit the growth and reproduction of microorganisms, ensure the	The interaction of cassava starch with the cell wall of microorganisms increases the activity	Frazão, G. G. S., and Blank, A. F., 2017

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			microbiological safety of perishable foods such as fruits.	of the coating.	
Lactobacillus	Carboxyl methyl cellulose and rosemary essential oil	Smoked eel	The method effectively reduces the number of lactic acid bacteria and inhibits the formation of oxidation products.	The combination of extract and coating played a synergistic inhibitory effect.	Azarakhsh, N., 2014
	Sodium alginate, galbanum gum and Ziziphora persica essential oil	Chicken fillet	The edible coating significantly inhibited the growth and reproduction of microorganisms after 12 days of storage.	The edible coating improved the ability of EO to enter cells and prolonged the antibacterial time of EO.	Hamedi, H., 2017
	Whey protein, Origanum virens essential oils	Sausages	Significantly inhibited the growth of foodborne	The coating prolongs the antibacterial activity	Catarino, M. D., 2017

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				pathogens in the sausage	of EO by sustained release	
	Escherichia coli	Chitosan-cassava starch, *Lippia gracilis* essential oils	Guavas	Good to keep the quality of guavas during storage	The combination of coating and EO increases the solubility of EO.	de Aquino, A. B., 2015
Gram-bacteria		Alginate-based, eugenol and citral	Arbutus unedo	The edible coating better maintains the sensory attributes and taste quality of *Arbutus unedo* during storage, and effectively inhibits the growth of spoilage microorganisms.	Edible coatings improve the dispersibility of EO.	Guerreiro, A. C., 2015
		Sodium alginate and lemongrass essential oil	Fresh-cut Fuji apples	This method significantly reduces the rate of ethylene	Eo solubility and adhesion were	Salvia-Trujillo, L., 2015

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			production, delaying the browning of the fruit.	improved	
Salmonella	Whey protein, origanum virens essential oils	Sausages	Significantly inhibited the growth of foodborne pathogens in the sausage	The combination of EO with the coating prolongs the antibacterial activity of the edible coating by sustained release and improves its dispersibility.	Catarino, M. D., 2017
	Chitosan-cassava starch, *Lippia gracilis* essential oil	Guavas	Good to keep the quality of guavas during storage	The combination of EO and chitosan-cassava starch significantly improved the antibacterial activity of the	de Aquino, A. B., 2015

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				coating.	
	Chitosan and lemongrass oil	Grape berries	Coatings can better preserve the microbial safety of grape berries.	Coating improves the solubility of essential oils	Oh, Y. A., C. 2017
	alginate-based, eugenol and citral	Arbutus unedo	Coating effectively extends shelf life of arbutus unedo.	EO coatings prolong antibacterial activity through sustained release	Guerreiro, A. C., 2015
Pseudomonas	Chitosan-cassava starch, *Lippia gracilis* essential oil	Guavas	This approach has the effect of inhibiting the growth and reproduction of Pseudomonas during storage.	The combination of EO and chitosan-cassava starch significantly improved the antibacterial activity of the coating.	de Aquino, A. B., 2015
	Carboxyl methyl cellulose and rosemary essential oil	Smoked eel	EO edible coatings inhibit the growth of	The combination of extract and	Azarakhsh, N., 2014

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		Pseudomonas and the formation of oxidation products	coating played a synergistic inhibitory effect.	
Tragacanth gum, Satureja khuzistanica essential oil	Button mushroom	Coating significantly inhibited the growth and reproduction of microorganisms.	The combination of EO and coating significantly increases the antibacterial activity of the coating.	Nasiri, M., 2017
Chitosan and bergamot essential oil	Grapes	Edible coatings preferably maintain the quality of the grapes during storage.	The combination of coating and EO improves the antibacterial effect of EO	Sánchez-G., 2011
Sodium alginate and citral and eugeno	Fresh raspberries	This method can effectively inhibit the growth of yeast, extending the shelf	Eo combined with coating has played a joint antibacterial effect.	Guerreiro, A. C., 2015

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Fungi	Yeast			life of raspberries.		
		Alginate-based and lemongrass essential oil	Fresh-cut pineapples	The coating may extend the shelf life of fresh-cut pineapples	The coating improves the dispersibility and solubility of Eo	Azarakhsh, N., 2014
		Chitosan and lemongrass oil	Grape berries	The coating can effectively inhibit the growth of yeast, and make the product maintain good color.	The combination of the coating with EO has synergistic bacteriostasis and prolongs the antibacterial time of EO.	Oh, Y. A., C., 2017
		Basil seed gum, *Origanum vulgare* subsp and *viride* essential oil	Fresh cut apricots	Yeast growth is inhibited, extending the shelf life of apricot.	Coating improves Eo dispersibility	Hashemi, S. M. B., 2017
		Tragacanth gum, satureja khuzistanica	Button mushroom	The coating effectively extends the	The combination of EO and	Nasiri, M., 2017

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essential oil		shelf life of mushrooms to 16 days.	coating significantly increases the antibacterial activity of the coating.	
Flaxseed gum, lemongrass essential oil	Pomegranate arils	Coating effectively inhibits the increase in the number of microbial populations, better maintain the intrinsic color of the samples	The coating increases the ability of the EO to enter the cell and improves the interaction between the EO and the cell.	Yousuf, B., and Srivastava, A. K. 2017
Cassava starch, chitosan and Myrcia ovata Cambessedes essential oil	Mangaba	This method is particularly suitable for controlling the growth of food-borne bacteria during storage of mangoes.	Edible coatings increase the solubility and prolong the antibacterial time of EO.	Frazão, G. G. S., 2017

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	Tragacanth gum and Zataria multiflora Boiss. essential oil	Button mushrooms	The method significantly inhibits the growth and propagation of yeast and prolongs the shelf life of mushrooms.	The combination of EO and coating significantly improved the antibacterial activity of the coating and delayed the release of EO	Nasiri, M., 2017
Botrytis cinerea	shrimp chitosan and *Mentha piperita* L essential oil	Grapes	The method effectively reduces the rate of decay of grapes during storage	Coating combined with EO increases the antibacterial activity of the coating.	Guerra, I. C. D., 2016
	Chitosan and lemon essential oil	Strawberry	The antifungal activity of strawberry was enhanced, and the respiration rate of strawberry during	EO combined with chitosan coating has a synergistic antimicrobial effect.	Perdones, A., 2012

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			storage was reduced.		
	Hydroxypropyl methylcellulose; Oregano and bergamot essential oil	Fresh‘Formosa’ plum	The coating significantly inhibited the increase in the total bacterial count of apples during storage.	The interaction between coatings and EO improves the dispersibility of EO.	Choi, W. S., Singh, S., and Lee, Y. S. 2016
Total bacterial count	Basil seed gum, *Origanum vulgare* subsp and *viride* essential oil	Fresh cut apricots	EO coating significantly inhibited the increase of total bacterial count, better maintained the quality of apricots.	The addition of the essential oil reduces the water vapor transmission rate of the coating and enhances the antimicrobial activity of the coating by associating with the coating.	Hashemi, S. M. B., 2017
	Sodium alginate,	Strawberri	The coating	The coating	

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Pectin, citral essential oils and eugenol essential oils	es	better preserves the physicochemical properties of the strawberry during storage and prolongs the shelf life of the strawberry.	increases the antimicrobial activity of the EO.	Guerreiro, A. C., 2015
Sweet potato starch and thyme essential oil	Shrimp	This method effectively prolongs the shelf life of frozen shrimp.	The coating increases the solubility and prolongs the antibacterial activity of EO.	Alotaibi, S., and Tahergorabi, R. 2017
Jujube gum and nettle essential oil	Beluga sturgeon	The coating significantly inhibited the growth of microorganism in fish and lipid oxidation	The effect of the coating on EO solubility improves their interaction with the cell membrane.	Gharibzahedi, S. M. T., and Mohammadnabi, S. 2017

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during
refrigerate
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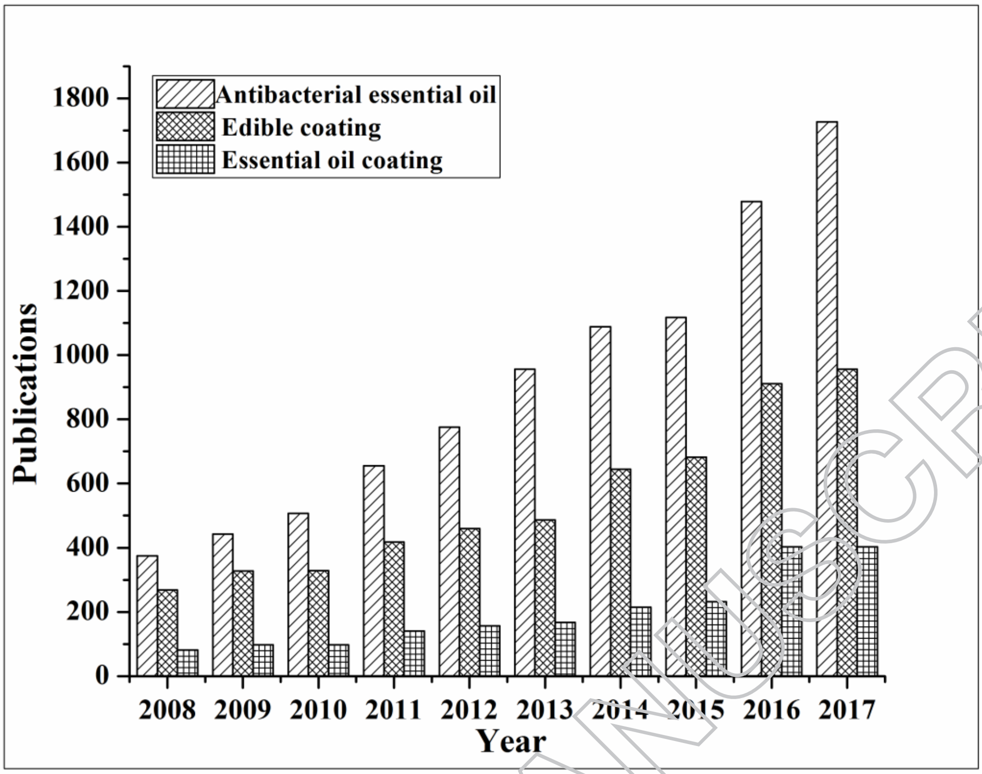

Figure.1. Number of publications indexed by Elsevier based on search strings related to the use of “essential oils as antimicrobials”, “edible coatings”, and “EOs-edible coatings” in the title and keywords of the publication.

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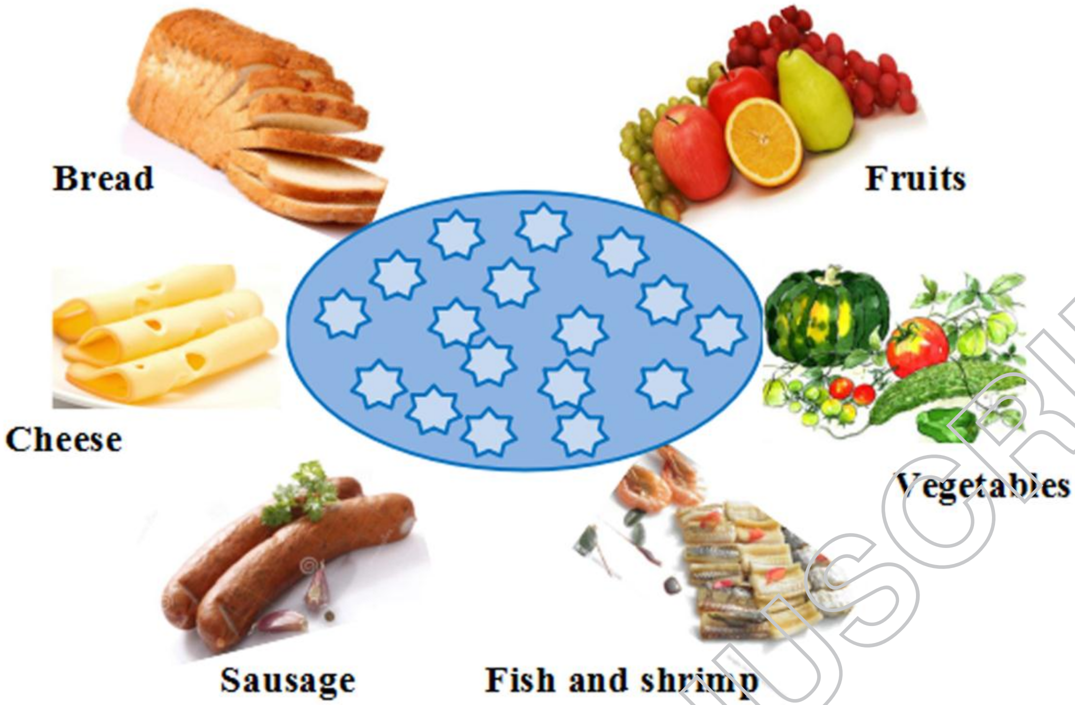

Figure.2. Potential food to be considered for EO-edible coatings applications.

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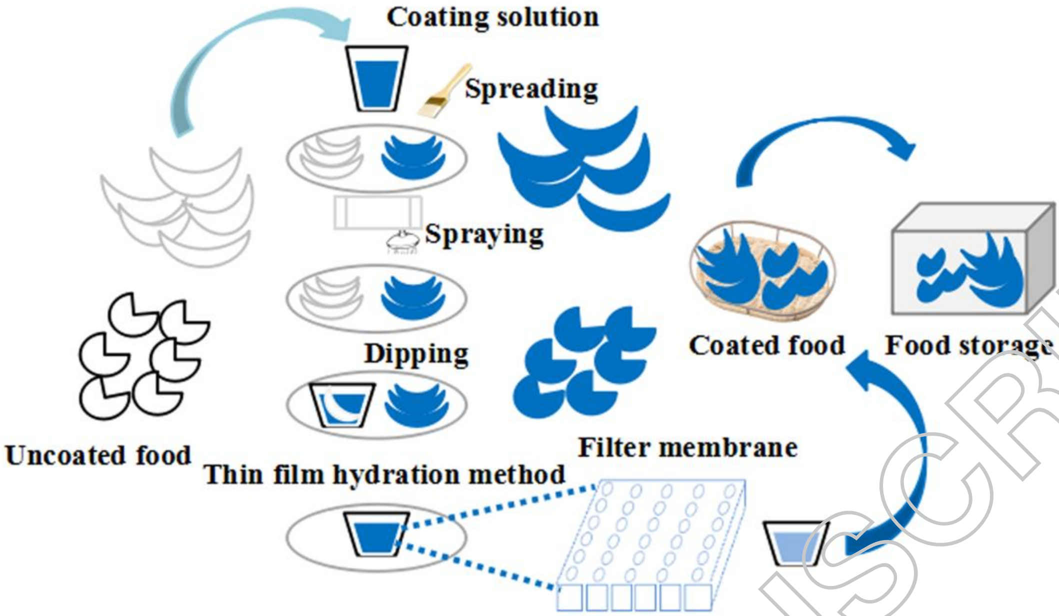

Figure.3. The production method of the EOs-edible coating and the application process in the food.

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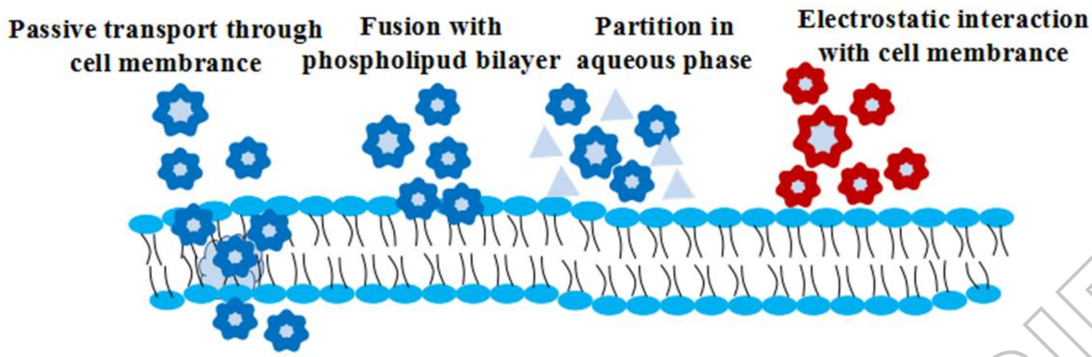

Figure.4. Schematics of the different routes promoted by the EOs-edible coating for the interaction of EO with the microbial cell membranes.

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