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Review Article

Fruits and Vegetables with a Coating that is Edible: A Review

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ABSTRACT

For increasing shelf life and preventing fruits and vegetables spoilage by microorganisms, edible coatings are among the procedures recently utilized for this issue. The biodegradable films use can be a source of saving energy and important issue for environmental protection. The preparation of edible coatings and films based on biomolecules as functional ingredient characterized by their antimicrobial, antibiofilm and antioxidant potential may help to ameliorate the safety and extend the food systems shelf life. Edible coatings have paid more attention from the food industry because of their, foaming and solubilizing characteristics.

Keywords: Edible coatings; Edible films; Food industry; Fruits; Vegetables

INTRODUCTION

From FAO data, around 1.3 billion tons of food is lost each year, which represent a 1/3 of the total amount of food manufactured worldwide. The highest rates of food waste are seen in European and North American nations. These losses per person in the European Union total about 170 kilograms per year. Besides economic losses, food waste has also led to wasted energy and water as well as increased domestic gas emission [1-3]. The spoilage by microbial action and oxidation procedures or by consumers is the most cause of food wasted [4-6]. Traditional preservation techniques like salting, heating, or adding chemicals are intended to prevent microbial growth in food, but they usually result in an undesirable loss of its nutritional content. Soft conservation procedures have played an important role in numerous foodstuffs. They are widely utilized instead of heat treatments to maintain the nutritional and sensory properties of food while maintaining product microbiological safety and a longer shelf life [4,7].

Coatings produce a changed environment that surrounds the product, just like the modified storage conditions do. The use of edible coatings on agricultural products, such as fruits and vegetables, has been the subject of extensive research. This modified atmosphere can protect the food from the time of coating application to its final retail destination and the consumer's home [8-10]. Most traditional packing materials are not recyclable or environmentally friendly [4,11,12].

The extending of shelf life and preserving organoleptic and nutritional characteristics of food are the main features sought in the coatings. Newly, edible films and coatings have gained more attention by scientists and food industry to replace conventional coatings [7,13].

Edible coatings must have acceptable organoleptic characteristics as well as sufficient biochemical, microbiological and physicochemical stability and can also be a means of reducing oxidative deterioration in foods [14-16]. Toxicological safety is imperative and their composition must comply with the regulations concerning the food concerned [17].

The edible film or coating serves a variety of purposes, including limiting the transmission of tastes, fats, carbon dioxide, oxygen, and water vapor; improving the mechanical integrity of the meal;

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and probably being the transport for food components or additions like antimicrobials or antioxidants [18]. These films are an integral part of the coated product and can be consumed at the same time as the product and therefore must have sensory properties, so as not to be detected during consumption because it can have an impact on the visual appearance (color, smooth appearance, shine, etc.), taste (salty, sugar, etc.), aroma or even texture [19-21].This review will describe various edible coatings and films applied in food.

LITERATURE REVIEW

Definition of edible coating and film

Thin layers of edible material are added to food products as coatings and films to extend shelf life while maintaining the best organoleptic quality [4,22,23].

Edible coatings and films have a similar definition, but there are some differences between the two. The first one is a thin layer of edible material that is an integral part of the food and can be consumed as it is, while the second is a thin layer of preformed film, consisting of edible material, which, when formed, can be placed on or between food components [7]. In addition, the edible coatings application is performed in liquid form straightly on the surface of the food to be coated [24-26], mostly by immersing the product in a solution, whereas edible films are independent structures prepared separately and moulded into solid sheets. These latter are subsequently added to the food item as a condition. While not acting as a package in and of itself, an edible film or coating can reduce the demands of the package's barrier [7,14,17,24]. If the bio packaging is not an integral part of the food and cannot be consumed at the same time as the food, but made from biomolecules, it will then be qualified as a biodegradable film. The latter is defined as a thin layer of materials completely degradable by microorganisms into natural compounds (CO_2, H_2O, C_2H_4) [21]. These coatings proceed like a barrier against water vapor, CO_2, oxygen, oils or aromatic substances [27-29].

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Edible coatings are mainly used to reduce gas exchange and undesirable chemical reactions, including weight loss during transport or storage. The result is therefore an extension of the shelf life and the quality of the food and the protection of the environment, because the packaging is not a waste [4,7,37,38].

History of edible coating use

Edible films and coatings have been traditionally used in food conservation, due to their capacity to ameliorate overall food quality, the appearance and food products shelf life [35,39]. The first known applications are very old, used in China from the 12^{th} centuries to delay the dehydration of citrus fruits with the waxes which were used to coat lemons and oranges [40] and in the case chocolate coatings for confectionery, or lipid films for meat products [24].

In the 15th century, the first edible film utilized for food conservation was fabricated from soy milk (Yuba) in Japan [41]. In 16^{th} century, the "larding", a layer of fat, was utilized in England to cover foods products to prevent humidity loss. For fresh fruits and vegetables after that, paraffin wax, carnauba wax, and emulsion oil-in-water coatings were used [42,43].

In 1839, Fastier had taken a patent to preserve the food to retain oxygen from the air. He arranged the tin with a hole in the lid, and heated it in a water bath, containing sugar or salty water. When he judged that the water vapor had driven out all of the air, he closed the box with a drop of solder and the use of calcium chloride [44]. In 20^{th} century, for preventing water loss, coatings were also utilized and added brilliance to fruits and vegetables. Shellac coatings permit candies to "smelt in the mouth and not in your hand" [45,46].

In the United States around 1930, molten waxes were applied to cover citrus fruits and oil-in-water emulsions on fruits and vegetables. It was from the 1950s that the use of edible films based on polysaccharides was suggested to protect apples from bleaching [42]. In 1967, edible films were mainly limited to wax coatings for fruits and vegetables. But from the year 1986, an important commercial use arose (about ten companies offering such products). This number was increased to 600 companies in 1996. Next, the edible films are employed with a large diversity of foods, with totally early revenue over taking 100 million US $[7]. In 2004, a regulation no. 1935/2004 was accepted and applied to all substances desired to come into contact with foodstuffs. Where, general requirements applicable to all these substances have also been established. After a risk evaluation procedure guided by the European Food Safety Authority the authorization of substances in contact with food has been submitted.

The European Commission, or the Council of the European Union, and the European Union then make a decision about risk management [47,48]. Several researches in the field of edible coatings have concentrated on compounds or multi components for exploiting the benefits of each constituent and for reducing their inconveniences [49-51].

Classification

Due to their skins, fruits and vegetables are distinguished by natural protection. These natural barriers have the ability to control permeability, biodegradability and maintain the food goodness by minimizing the loss of flavor and aromas. However, food technology seeks to improve these natural barriers called edible coatings [52-54]. Biodegradable edible coatings are generally grouped in accordance with their structural material [7,55,56] (Table 1). The main compounds that make up edible coatings are split into 3 classes: Hydrocolloids (protein and polysaccharide), lipids and composites (a mixture of different compounds) [52,57].

Hydrocolloides

Due to their superior mechanical and structural qualities, hydrocolloids are the biopolymers that are most explored for the creation of edible coatings. Their films are generally soluble in water and therefore have low resistance to water vapor. But they are good barriers for O_2 and CO_2. They are represented by polysaccharides and proteins [37,58].

Polysaccharides: Polysaccharides are widely used as edible coatings. They can be synthesized from various sources: Alginates, cellulose, pectin, starch (native and modified), agar, carrageenan, chitosan and gum exudates, etc. (Table 1). Polysaccharide-based coatings are usually highly hydrophilic [59-61]. Most are neutral, but the gums are charged negatively. Numerous hydroxyl and other polar groups are presented in the polysaccharides, making the hydrogen links with a pivotal function in film development [7].

Polysaccharide-based hydrophilic coatings delay the loss of moisture in food products. They are "priest-agents". The utilization of polysaccharides inhibits surface dehydration of certain fresh or frozen foods. They dehydrate before the product and form a protective film [42]. The two most commonly utilized edible polysaccharide-based coatings are various gums and chitosan [41]. The gums dissolve in water as a result of hydrogen bonds forming between the polymer and the solvent. These polymer molecules can be rearranged as micelles in solutions. During drying, these micelles are stable and form a film [7,61].

The study by Haq et al., [62], shows that samples of Chilgoza (*Pinus gerardiana*) coated with Cordia gum containing Cordia myxa extract had the highest increase in shelf life (about 95%), followed by Carboxy Methyl Cellulose (CMC) and C. myxa extract (about 60%), then Cordia gum (about 25%) and then CMC (about 15%). However, the treatment of chilgoza samples with alpha-tocopherol did not improve the rate of oxidation stability. Alginates are considered as dietary fiber well known by their pharmaceutical activities, especially on intestinal absorption and treatment of stomach ulcer. This capacity is related to high number of mannuronate residues that could provoke cytokine production 10 times more than alginates include inggreatrate of guluronate residues [38]. Alginate-based films are impermeable to lipids [63-67].

Chitosan is among the most abundant polysaccharides in nature. This polysaccharide is derived from chitin and consisting of ß-(1-4) bound D-glucosamine and N-acetyl-D-glucosamine. It is a non-toxic product with a powerful antimicrobial effect, biodegradable and applied as a coating of fruits and vegetables. Chitosan coating reduces enzymatic browning and delays color change and reduces weight loss [35,68]. By dint of their antitumor, antiviral, anti-inflammatory, immunomodulator, antithrombotic and anticoagulant activities, sulphate polysaccharides called carrageenan extracted from edible red algae are most often employed for coating of fruits and vegetables [69].

Additionally, micro-algal exopolysaccharides and other lactic acid bacteria are also involved in edible coatings preparation for various foods because of their multi functionality [38,70,71]. In the research of Ghasemzadeh et al., [72], three edible coating materials (pectin, vegetable gum and starch) were studied to preserve two varieties of raisins (Thompson without seeds and Shahani). The evaluation of chemicals, microbial and sensory properties after 6 months of storage period showed that pectin coating was better than gum and starch coatings.

Proteins: Proteins are biodegradable polymers and very much in demand in food technology. They are particularly important for manufacturing edible films and coatings like animal derivatives (for example, casein, whey protein isolate and concentrate, collagen, gelatin, keratin, and egg albumin) or plants (soybean, corn, cottonseed, wheat, rice and peanut) (Table 1) [7,38]. The mechanism of protein-based film formation includes the protein denaturation the by heat, solvents and pH modifying, accompanied by a combination of peptide chains with other intermolecular interactions [7,73,74].

Lipids

Edible coatings founded on hydrophobic compounds like lipids have often been utilized in the food field. Hydrophobic substances, particularly those with high melting points, are effective barriers to the transmission of moisture from food [4,27]. According to their water vapor permeability, wax (vegetable or animal) has the highest water barrier efficiency, followed by high melting temperature greases (>35°C), lacquers and natural resins, esterified mono- and diglycerides, fatty alcohol and emulsifiers and active surfactants; while the lowest one is low melting point fatty acids and fats (<20°C) [75].

Several lipid molecules of different origins (natural waxes and derivatives, acetoglycerides, etc.) can be used (Table 1) [37,58]. Fats cannot produce coherent, independent films because they are not biopolymers, in contrast to polysaccharides and proteins. In addition, it is possible to observe stability problems of the product coated by lipids, in particular oxidation, texture changes and organoleptic quality with a taste of waxes [7,76]. The solid lipids forming the coatings can become thicker and brittle with low mechanical resistance. Lipids have been known by their filmogenic properties and for their hydrophobic character offset in composite materials. Depending on their concentration in the final formulation, they will be considered as additives or as part of a composite.

The kind and quantity of interactions, or bonds, between the film and support determine how well a coating adheres to the surface of food products [63,77,78].

Composites

A composite formulation can be created by a mixture of proteins or polysaccharides associated with lipids (Table 1). Composite films could ideally combine the water, be barrier of oil, oxygen and other components [75,79,80]. These mixtures of compounds form a similar film layer, or a multilayer film and or in the form of an emulsion. These edible coatings are applied so as to obtain the best characteristics of each constituent, minimize their disadvantages and overcome their respective drawbacks [4,19]. They can be used to prevent enzymatic browning or to retain the aroma of certain fruits such as bananas, mangoes, papaya or tomatoes [78,81].

Antimicrobial films can be processed involving different organic acids (citric acid, sodium diacetate, sodium lactate and potassium sorbate), nanomaterials food additives and natural preservatives (polyphenols and essential oils) in chitosan matrix. These composites have impacts on lipid oxidation, proteolytic and microbial decomposition [7,82]. Depending on the nature of the molecules employed in the polymer matrix and their affinity, the composites demonstrate the mechanical properties of the films [83-85].

Calcium solubility, moisture content, film thickness, and mechanical characteristics of sodium alginate and pectin compounds are all impacted by the addition of cross-linking materials like $CaCl_2$ [83,86]. Lipid coatings can affect the transparency of the food. Nevertheless, when hydroxypropyl methylcellulose has been mixed with fatty acids, its composite films become less transparent and lower water vapor permeability compared to the same lipid-free film. The formed composites are more stable where the similar and ongoing lipid layer is within the hydrocolloid matrix [58,87,88].

Class		Examples of compound	Examples of fruits or vegetables	References
Hydrocolloids	Polysaccharides	Chitosan Carrageenanes, Alginate, Chitosan-rice Carboxy methyl cellulose, Pectin Chitosan Cassava starch	Cut papaya, Tangerine Cut apple, Peach Pomegranate Grapefruits, Strawberry Fresh melon Fresh-sliced okra Strawberry	[7,14,35,63,68,70,89]
	Proteins	Soy proteinisolate bacteriocins, casein, whey, collagen, gelatin(fish or meat origin, and egg albumin) protein (from corn, wheat soy, cottonseed, peanuts and riz) gluten, milk proteins (casein, whey protein isolate)	Banana Tomatoes	[7,14,89]
Lipids		Carnauba wax Paraffin acylglycerol, fatty acids and waxes	Orange fruit Mango Papaya or tomatoes	[14,37,89]
Composites		Poly Lactic Acid	Mango, Cut apple	[7,14,38,189,101]

	Chitosan/poly-ε-lysine	Table grapes (*Vitis vinifera L.*)
	Chitosan/cellulose	Black grapes
	Sodium alginate-gum	
	Alginate/pectin	
	Carrageenan/alginate-lipid	
	Carrageenan/alginate Carrageenan/alginate-inorganic particles Carrageenan/alginate	
	Chitosan (CMC)-Guar gum	
	Starch/sodium caseinate, Organic acids, essential oils	

Table 1: Main substances used in structural matrices of edible coatings.

Methods of edible coatings application on vegetables and fruits

The different methods were used for applying edible coatings on vegetables and fruits [89].

Depending on the application of coating techniques, two broad classes of processes can be classified: Continuous processes and discontinuous processes [20,90]. Continuous processes employ several different techniques: Rotating cylinder (snacks, sweet cereals), screws (pet foods), coextrusion (sausages, snacks), fluidized bed for air fluidization, spraying and drying (seeds), conveyor (topping of pastries). Discontinuous processes are techniques involving a mobile arm mixer (seed) or a mobile tank mixer (deep-freezing).

According to Moradi et al., [71], several criteria will describe the choice of one of these two processes. The main characteristics of the product (shape, apparent density); the degree of coating (partial, total); the mechanical strength of the product; the thickness of the layer; the duration of the treatment, etc.

Dipping method: The only technique for creating extremely thick edible coatings on fruits, vegetables, and animal products is dipping. Surface tension, viscosity, and density of the coating solution are all factors that affect the film's thickness. This method was applied to preserve the papayas by a carrageenan-based coating and also to coat the carrot with sodium alginate. The procedure involves dipping the product into the coating formulations' aqueous medium, removing it, and allowing it to air dry to create a thin membrane layer on its surface [38,91,92].

Spraying method: This technique is based on electrospraying of a low viscosity solution. This method is easily applied at high pressure (60-80 psi) [38,93].

Brushing or spreading method: The coating solution used in this method is spread over foods such as the coating of dog biscuits with sodium alginate [38,94,95].

Advantages and disadvantages of conventional edible coating

Reducing food waste is a major global challenge. The growing interest in edible coatings has been driven by rising consumer demand as they wrap food products and make them more attractive [24,96]. Recently, edible coatings and films have received considerable attention to extend the shelf life of the food product due to their advantages over synthetic films [53,96,97,98]. Biofilms are fabricated by using edible products and usually extensible resources, and in nearly all cases their degradation is easier than polymer matters. They will participate to the ecological pollution decrease [7]. Most importantly, their consumption is possible and safe with canned products [59]. Edible coatings supply an enrichment of the natural sheets on the product outside to preclude loss of water, aromas and gas movements, which are involved in the respiration of food products [76]. Freshness, improved organoleptic quality, health safety (a safer product, which reduces microbiological development), and waste reduction by using less plastic are other crucial factors [96].

Combining primary and secondary edible non-food packaging can boost the capacity to preserve food, even if edible films and coatings are not intended to replace conventional packaging. Secondary packaging is often utilized for sanitary and hygienic purposes [7]. The integration of antibacterial agents and antioxidants helps to delay oxidation and microbial deterioration. Nevertheless, their permeability and mechanical characteristics are commonly lower than synthetic films, which limit their use. But further research succeeded in overcoming some of these limitations [42,7].

La combinaison de matériaux hydrophiles et de molécules lipidiques hydrophobes permet d'obtenir des films dont la fonctionnalité est supérieure à celle des films hydrocolloïdes purs in particular their humidity barrier characteristics. These composites are possibly gained as bi-sheets or emulsions. Lipid founds the second layer on the polysaccharide or protein layer in a two-layer composite system. However, lipid is distributed in the biopolymer matrix in the emulsified structure. These composite characteristics rely on the elaboration approaches, type and quantity of the constituents. The major inconvenient of two-layer films is that the method of preparation steps casting and drying.

Despite providing effective water vapor barriers, laminated films are less common in the food sector. The investigation has also exhibited that bilayer films resort to peel off over time, promote holes or cracks, and reveal non-uniform area and cohesion characteristics [18,99]. Beyond the recommended dietary doses, coating agents may present health risks [24,100].

The results of the survey carried out by Ellouze et al., [96], allowed to report some disadvantages which are mainly related to the notion of hygiene and safety against the ingredients of the coating (unknown risk of the components on health).The problems of use and appearance of the product (possibility of removing the film, resistance to cooking, freezing, etc.), the cost (increase in the overall price, cost of the film), the lack of regression on the product (new product, questions about possible negative effects, mistrust), taste of the coating (alteration of the taste of the food). Finally, the respondents were asked to evaluate the qualities of the edible.

CONCLUSION

Edible coatings and films are regarded as a secure substitute to lessen the harmful effects of conventional ones on the environment and public health. To increase the shelf life of fruits and vegetables, various biomolecules are used to create edible coatings and films. Alternative strategies are needed for improving the edible coatings producibility and lowering the production and processing cost. Therefore, process development and research must focus on biomolecules that can be recovered using a simple and inexpensive methodology as one of the methods to create edible coatings as a potential replacement for their chemical equivalents.

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AUTHOR STATEMENT

H R: Writing-review and editing; **TA:** Writing-review and editing; **O-N K:** Writing-review and editing. **Z A:** Writing-review and editing; **P R:** Writing-review and editing.

DATA AVAILABILITY

All data generated or analysed during this study are included in this published article.

DECLARATIONS

Consent to participate

All authors approved the manuscript.

Consent for publication

Written informed consent for publication was obtained from all participants.

CONFLICT OF INTEREST

The authors declare no competing interests.

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