A REVIEW ABOUT EDIBLE FOOD COATINGS AND FILMS

A Thesis

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ABSTRACT

For centuries, to enhance the shelf-life and quality of foods, edible films and coatings have been used. These materials are eco-friendly biodegradable and non-toxic materials that can protect the food products against microbiological pathogens, reduce deterioration, and minimize lipid oxidation and moisture loss of food products. This paper presents different material selections and their applications, classified by chemical components including polysaccharides, lipids, proteins, and composites. Moreover, agro-industrial residues/wastes are also mentioned as a new material resource, with the benefits of reducing food waste, being environmentally friendly, contributing to sustainability, being economical, and possibly providing some health benefits. In addition, the main production methods, additives, and characterization are also introduced.

BIOGRAPHICAL SKETCH

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Finally, I would like to thank my parents, family and friends, even though we are separated by time difference and geographical distance, we are never apart mentally.

The beautiful scenery of Ithaca made me feel worthy at many moments. So I 'll end with an excerpt from one of my favorite poems:

“The woods are lovely, dark and deep,
But I have promises to keep,
And miles to go before I sleep,
And miles to go before I sleep.”
- *Robert Frost, “Stopping by Woods on a Snowy Evening”*

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1. Introduction

Edible coatings and films are thin layers applied on food products to protect them and improve their quality. They are prepared from naturally occurring renewable sources (polysaccharides, proteins, lipids and composites) which we can eat without disposing them (Hassan et al., 2018). Edible coatings and films generally not exceeding 0.3 mm and formed directly on the food surface or between different layers of components to prevent the migration of moisture, oxygen, and solute into the food (Lacroix & Vu, 2014). There is a lack of consensus regarding the differences between a film and a coating. In most cases, the terms film and coating are used interchangeably to indicate that the surface of a food is covered by relatively thin layer of material of certain composition. However, they can be differentiated by the notion that: an edible film is a standalone material, with the layer previously shaped and can be wrapped around the food, whereas the edible coating is an exterior layer which remains attached to the coated food (Dhaka & Upadhyay, 2018; Kocira et al., 2021; Pavlath & Orts, 2009). In conclusion, a film is a stand-alone wrapping material, while a coating is created directly on food surface itself (Brychcy-Rajska, 2017). In this study we are going to talk about the mechanisms and methods of preparation of these edible coatings and films, the possible materials and applications, the potential active ingredients to be used in them and the most common characterization techniques (**Figure 1**).

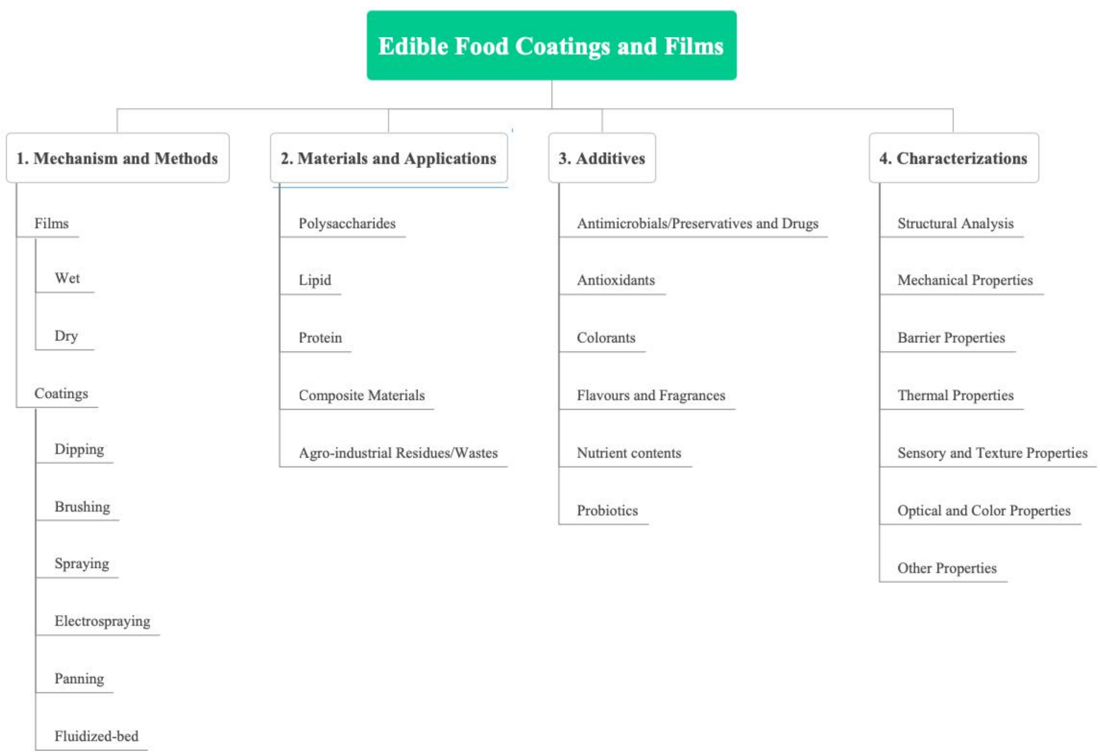

Figure 1. The schematic overview of the current study

As edible coatings and films provide alternatives to conventional synthetic plastics, they are more environmentally friendly. Various bio-based polymers used as the materials have been investigated, such as hydrocolloids, which are the most commonly used materials in the production of edible coatings and are formed by polysaccharides and proteins. However, those materials are hydrophilic, which means poor water vapor barrier properties, different types of lipid are combined with the hydrocolloid matrix to address the problem. Moreover, extensive research has focused on composite edible coatings (the combination of two or more coating-forming substances), since they could provide more advanced functional properties. Optimize the materials, composition, properties of edible coatings and makes them more economical are new research trends.

In terms of nutritional and economic impacts, it takes considerable time for food products before reaching the table of the consumer, and damage can occur at various stages, such as handling, storage and transportation, where the product begins to dehydrate, deteriorate, and lose its appearance, flavor and nutritional value. This damage occurs all the time, even if it is not immediately visible, and if no special protection is provided, the damage may reach an effect that affects consumption in a matter of hours or days (Pavlath & Orts, 2009). Edible coatings can protect the food products from microbial contaminants, prolong the shelf life, reduce the effects of spoilage, and minimize lipid oxidation and moisture loss. The materials used for edible coating are biodegradable, and non-toxic, as they are developed from various types of biopolymer matrix (Galus et al., 2020).

2. Mechanism and Methods

2.1. Mechanism

Edible coatings provide a barrier to oxygen, microbes of external source, moisture and solute movement for food. A semi permeable barrier is provided by edible coating and is aimed to extend shelf life by decreasing moisture and solute migration, gas exchange, oxidative reaction rates and respiration as well as to reduce physiological disorders of fruits and vegetables (chilling injury etc.). Properties of edible coatings are based on their molecular structure, molecular size, chemical composition, also other adding active ingredients, like antimicrobials, antioxidants, colorants, flavors and fragrances, nutrient contents and probiotics.

2.2. Preparation Methods

Edible films are produced mainly by 2 methods, which are wet and dry methods. Wet method, also known as solvent casting (Galus et al., 2020), which can be divided into bench and continuous castings. Among wet processing, films can be obtained by evaporation of the solvent. Dry method, also known as extrusion, can be subclassified into extrusion, injection molding and thermoforming (thermo-pressing) methods. Thermoforming method is mostly laboratory scale, whereas, extrusion and injection molding methods are mostly used in industrial and commercial scale and are highly efficient.

Edible films are produced mainly by 6 methods, which are dip coating, brushing, spraying, electrospraying, panning and fluidized-bed. A suitbale choice between these methods will have direct effect on the final products quality. The selection is based on the food characteristics (e.g. affinity between the surface and coating solution), desired thickness of the coating, drying method and rheological and physicochemical properties of the coating material. In all the coating methods, the coating solution wets the products surface and penetrates into the skin or surface (Monteiro Fritz et al., 2019).

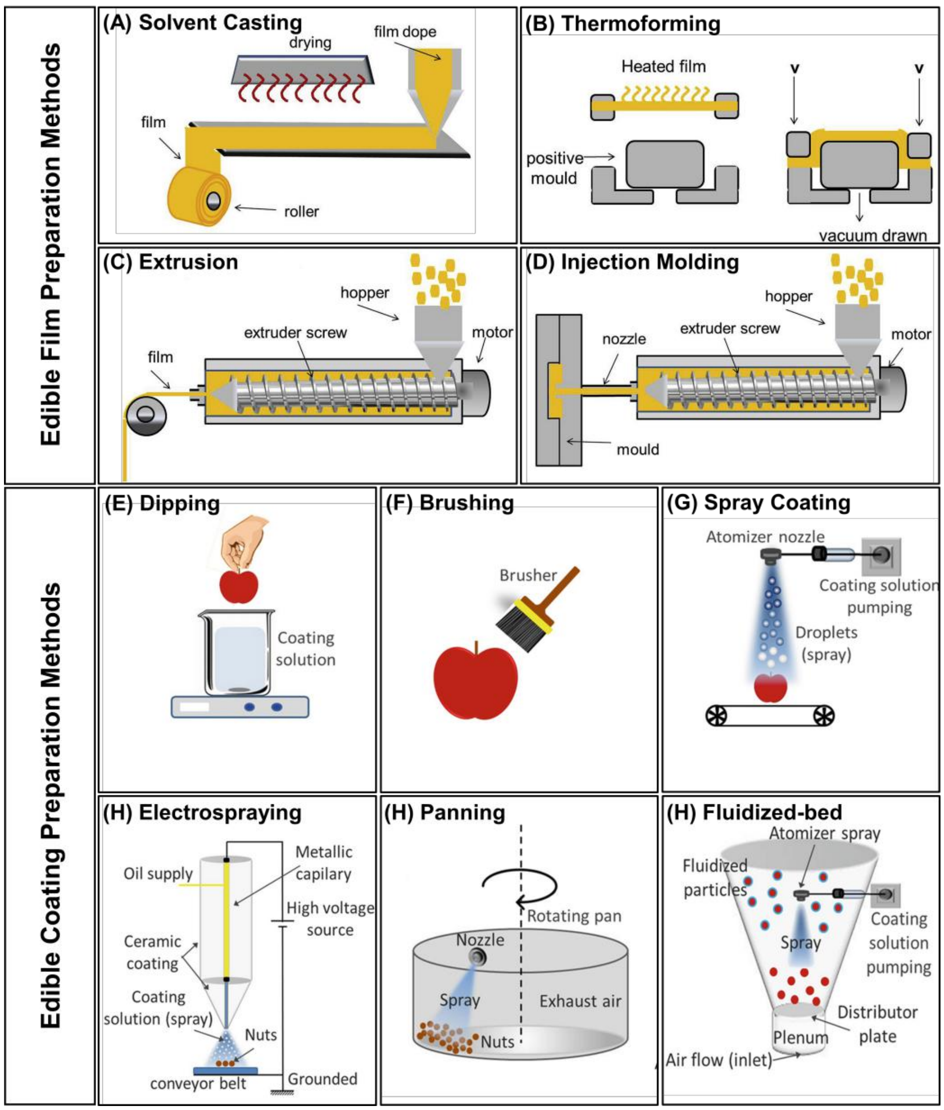

Figure 2. Schematic representation of edible film and coating preparation methods (A) solvent casting, (B) thermoforming, (C) extrusion, (D) injection molding (E) dipping (F) brushing, (G) spraying, (H) electrospraying, (I) panning, and (J) fluidized-bed (Kouhi et al., 2020; Monteiro Fritz et al., 2019)

3. Materials and Applications

Edible coatings and films are produced from polysaccharides, lipids, protein or the composite of them. As people's increasing concern about environment, the resource of agro-industrial residues/wastes becoming an attractive novel material choice.

3.1. Polysaccharides

Polysaccharides-based materials including Cellulose and derivatives, Chitin and chitosan, Starch, Pullulan, Pectin, Alginate, Carrageenan and Agar, Galactomannans(Acacia Gum/Gum Arabic, Tara gum, Guar gum), Xanthan gum, Mastic Gum, Plant Gum, and Mucilage. Polysaccharides show poor moisture barrier properties (hydrophilic nature lead to water adsorption) which means polysaccharides-based materials cannot provide protection against water transmission or absorb water and provide temporary protection against further moisture loss. Moreover, these materials are moderately less permeable to O_2 and selectively permeable to O_2 and CO_2, which means they are suitable for preservation of fruits and vegetables where they can reduce the respiration rate (Brychcy-Rajska, 2017; Pavlath & Orts, 2009).

3.1.1. Cellulose and derivatives

Cellulose and derivatives are composed by a linear chain with two anhydroglucose rings. They mainly come from wood, cotton, hemp and plant-based materials, which can also be synthesized by tunicates and microorganisms. They are insoluble in polar solvents, however, soluble in a few solvents which have no similar chemical properties. Thus, dissolve or chemical treatments is needed to change them to water-soluble cellulose derivatives. They have many great features, such as great film-forming function, tasteless, transparent, odourless, bendy, and are of low energy, resistance to oil and fat, hydrophilic in nature, moderate to O_2 diffusion and moisture.

Cellulose and derivatives have been used in many applications, such as in fried foods to block the absorption of oils(Balasubramaniam et al., 1997), like potatoes(García et al., 2002). Or used in confectionery foodstuffs and act as barrier to lipid(Nelson & Fennema, 1991). Or just used in vegetable and fruits, like cherry tomatoes(Fagundes et al., 2015), to reduce weight loss, maintain peel color and fruit firmness, control respiration rate and improve sensory attributes.

3.1.2. Chitin and chitosan

Chitosan can be primarily transformed from chitin - composed of N-acetyl-d-glucosamine units - by deacetylation in concentrated alkali solution. They can be obtained from the shells of crustaceans, mostly crab and shrimp shell wastes, and many other organisms, including insects and fungi. They are insoluble in water and in common organic solvents, with the low solubility in neutral and basic solutions - the solubility depends on the degree of N-acetylation (DA) and molecular weight (Mw).

They can formate a continuous layer, and build clear, bendy, strong crystal, with good gas barrier properties. They are partial permeable, therefore diminish transpiration rates and retard ripening. With antimicrobial attributes and high viscosity. When applied as an antioxidant and antifungal agents, such as identifying the optimum concentration of chitosan coating solution in order to retard oxidation and fungal growth without undesirable effects on sensory properties of the final product. Not thermoplastic as it degrades before the melting point, cannot be extruded or molded and the films cannot be heat-sealed, can blend with thermoplastic polymers to improve thermal properties.

Chitin and chitosan have been used in many applications, such as in fruits and other agricultural commodities(Rosyada et al., 2019) to strengthen the mechanical properties, help maintain sensory qualities of taste, color and avoid water loss(Chien et al., 2007) to increase their shelf-life(Martiñon et al., 2014). Or used as antimicrobial(Ghaouth et al., 1991). It can also be used in meat products, like beef(Cardoso et al., 2016), to keep the color and avoid lipid oxidation during retail display. Or used in nuts, like walnut kernel(Sabaghi et al., 2015), to optimize the effects on lipid oxidation, fungal growth, and sensory properties.

3.1.3. Starch

Starch, mainly from the storage organs as the roots of the cassava plant, e.g. the tuber of the potato and the seeds of corn, wheat, and rice. Starch is insoluble in cold water, however, which can have a partial solubilisation when heated in water. Heating starch suspensions in excess of water between 65 and 90 °C, depending on the type of starch, an irreversible gelatinization process will happen. To obtain a homogeneous film-forming solution of starch, need to gelatinize the granules in an excess of water (>90% wt/wt). Starch is transparent, odorless, tasteless, and good gas barrier, hydrophilicity, accurate mechanical properties. Modified starch is also a new available material. Compared to virgin starch, modified starch granules exhibit higher straight-chain starch content, reduced swelling and increased hydrophobicity(Sondari, 2019).

Starch edible coatings are also used as antioxidants and anti-microbial agents(Homayouni et al., 2017), for example, to enhance the antimicrobial activity of chicken sausages(Marchiore et al., 2017). It can also be used for fruit and vegetable products, such as brussels sprouts(Viña et al., 2007), to enhance shelf life by optimizing weight loss, surface color and texture.

3.1.4. Pullulan

Pullulan, a polysaccharide polymer consisting of maltotriose units, also known as "α-1,4- ;α-1,6-glucan", which can be synthesized by the yeast-like fungus *Aureobasidium pullulans* and is soluble in water. It owns good adhesive properties, high mechanical strength. Also, colorless, tasteless, and odorless and have limited permeability to gases such as oxygen and carbon dioxide. Moreover, as a polysaccharide, it will not be used by bacteria and fungi that lead to the spoilage of food.

Studies have shown that pullulan can be used to improve the color, appearance and sensory attributes of apples during cold storage(S. Wu & Chen, 2013).

3.1.5. Pectin

Pectin, a component of plant fibre and can be extracted from the plant cell walls. Commercial pectins have mainly been obtained from apple pomace and citrus peel. It can soluble in water. Pectin can be classified to 2 types: high methoxyl pectin (HMP, degree of methylation > 50%) and low methoxyl pectin (LMP, degree of methylation < 50%), which will influence the properties of pectin. HMP are better, with more outstanding mechanical, water barrier properties and thermal stability. Pectin have excellent extensibility but poor moisture barriers, therefore, which is recommended for food with low moisture content.

When used as an edible coatings, pectin can be used to protect fruits, such as raspberries(Guerreiro, 2016) and apricots(Genevois et al., 2016), controlling color, soluble solids concentration, weight loss, barrier properties, antioxidant capacity, microbial growth and flavor. Or it can be used in meat products, such as cooked pork patties(Kang et al., 2007), to maintain their physicochemical, microbiological and organoleptic qualities.

3.1.6. Alginate, carrageenan and agar

Alginate, Carrageenan and Agar are all obtained from seaweed product, mainly from species of marine algae, belonging mainly to Phaeophyceae (brown algae) and Rhodophyceae (red algae).

3.1.6.1. Alginate

The sodium salt of alginate is a brown seaweed product. Alginate is not permeable to fats and oils, but is soluble in water and has a high water vapor permeability. It is able to react irreversibly and immediately with divalent and trivalent metal cations (Ca^{2+} and Ca^{3+}) and form water-insoluble polymers. Alginate has distinctive colloidal properties such as thickening, gel formation, film formation, and can be used as emulsion stabilizer, capable of forming suspended films or coatings, and the films formed are uniform, transparent and glossy in appearance. It has the advantage of reducing the shrinkage of food products and maintaining their moisture, color and odor.

Alginate is most frequently used on fruits, such as fresh-cut melons(Oms-Oliu et al., 2008) or apples(Rojas-Graü et al., 2007), to extend shelf life, maintain their color, firmness, sensory qualities, and have some antimicrobial properties.

3.1.6.2. Carrageenan

Carrageenan is derived from the cell wall of red algae. It can be divided into carrageenan (κ-carrageenan), iota carrageenan (ι-carrageenan) and lambda carrageenan (λ-carrageenan). Carrageenan is soluble in water and its solubility in water depends on the content of sulfate ester and related cations. The higher the sulfate ester content, the lower the dissolution temperature. And the presence of cations such as Na, K, Ca and Mg promotes cation-dependent aggregation between carrageenan helices, which leads to lower solubility. In applications, carrageenan is usually used as a coating rather than a film. The most common of the three carrageenans is κ-carrageenan, which can be frozen and thawed to form a coating that is opaque but can be made transparent by the addition of sugar. In the presence of potassium (K) salts, it forms strong and hard gels, while in the presence of calcium (Ca) salts it forms brittle gels. As for ι-carrageenan, in the presence of calcium (Ca) salts, it forms elastic and transparent gels with no syneresis, which means no separating out of liquid and can form a stable structure.ι-carrageenan possesses good mechanical properties and can be used as an emulsion stabilizer, reducing O_2 transfer, limiting surface dehydration and deterioration of fruit flavor. λ-carrageenan does not form gels, but only highly viscous solutions. Carrageenan can be used to protect vegetables and fruits from water loss, oxidation of compounds and aging processes, in combination with ascorbic acid to reduce the number of microorganisms.

Some studies have shown that Carrageenan can be used on pumpkins to provide color protection and antibacterial effects(Genevois et al., 2016).

3.1.6.3. Agar

Agar, a mixture of agarose (gelling fraction) and aglycone (non-gelling fraction). Agarose is derived from red seaweed and is the support structure in its cell wall, which is the source of the gelling properties of agar. Agar is soluble in water and has a higher strength and melting point compared to κ-carrageenan, probably related to the lower content of anionic sulfates. It can form form strong, thermally reversible gels and form transparent, hard, insoluble films in water.

Agar can be used on beef to retard lipid oxidation and microbial spoilage, while effectively maintaining texture and odor characteristics(B. Zhang et al., 2021).

3.1.7. Galactomannans

Galactomannans are industrial polysaccharides isolated from the seeds of guar, carob, fenugreek and tara plants(Kontogiorgos, 2019). It is a heteropolysaccharide consisting of a mannose backbone with galactose side groups.

3.1.7.1. Acacia gum/Gum arabic

It belongs to the arabinogalactan-protein complex, a gelatinous exudate from the stems and branches of Acacia species. This material is water soluble, less viscous, more soluble and has good emulsifying and film-forming properties.

Acacia gum helps to preserve the quality and extend the shelf life of post-harvest bananas by protecting the firmness of the fruit, reducing weight loss, maintaining reducing sugars and titratable acidity levels(La et al., 2021).

3.1.7.2. Tara gum

Derived from the seeds of Caesalpinia spinosa tree. Tara gum is water soluble, with high viscosity, strong water binding ability, and can synergize with other polymers, but has relatively poor mechanical and water vapor barrier properties. Strong films can be formed because of the possession of fewer galactose substitutes compared to guar gum or other galactomannans.

Tara gum can be used as an antioxidant and antimicrobial agent or in conjunction with low methoxylated pectin films and to improve their physical properties(Chen et al., 2020).

3.1.7.3. Guar gum

Derived from the seeds of Cyamopsis tetragonoloba. Due to the large number of hydroxyl groups, guar gum is soluble in water, but the phosphate cross-linking in it reduces its solubility. It can be used to form homogeneous edible films.

Guar gum can be used on strawberries to act as an antimicrobial agent and slow down spoilage(Aydogdu et al., 2020).

3.1.8. Xanthan gum

Derived from the submerged aerobic fermentation of pure cultures of Xanthomonas campestris, it is an extracellular heterogeneous polysaccharide. It is soluble in cold water and has a high degree of pseudoplasticity - viscosity decreases when shear stress increases. It appears as a highly viscous solution at low concentrations and is able to stabilize viscosity over a wide pH and temperature range. It can also be used as an additive to starch-based films to improve some of their mechanical properties.

Xanthan gum can be used to maintain the quality attributes (color, hardness, weight loss, water loss) of fresh-cut pears at 4℃ (Sharma & Rao, 2015).

3.1.9. Mastic gum

Mastic gum is a plant resin obtained from a special kind of pistachio, a species of the lentil tree (family: Ancardiaceae), and is a yellowish natural resin produced from the bark of the evergreen frankincense shrub *Pistacia lentiscus*(Guerreiro, 2016). It is soluble in oils and organic solvents and insoluble in water. It can be made into a variety of shapes and has excellent film-forming abilities, as well as antibacterial, antioxidant and anti-inflammatory properties. It has been used in certain semi-solid products, such as ice cream and bakery products, as a flavoring or antimicrobial agent and as a texture modifier(Terpou et al., 2018).

Mastic Gum can be used to protect peeled fresh almond kernels by providing an effective barrier against oxygen penetration and moisture, for antioxidant and antibacterial effects(Farooq et al., 2021).

3.1.10. Plant gum

Plant gum is a polysaccharide/carbohydrate polymer derived from the woody parts of plants or in seed coatings. Plant gums are pathological and extracellular components that are damaging to the plant when the cell wall is disrupted due to injury or due to unfavorable conditions such as drought. Plant gum is a hydrocolloid (forms a gel or sticky substance in the presence of water), is readily soluble in water and forms a gel, and is insoluble in common organic solvents. Properties vary with various factors, such as extraction and purification techniques, age of the plant and growth conditions.

Plant gum has a wide variety of species. Polysaccharides from A. occidentale L. tree gum can improve the maintenance of apple quality by improving water vapor permeability, film opacity and mechanical properties(Carneiro-da-Cunha et al., 2009). It has also been found that edible films based on basil seed gum (BSG) containing fats (including caprylic, lauric and palmitic acids) can be made edible and pH-sensitive on an industrial scale by blending and thermoforming(Hashemi Gahruie et al., 2020).

3.1.11. Mucilage

Mucilage is similar to plant gum,as they both are hydrocolloids. However, Mucilage is a normal physiological metabolite formed in the cells of plants under natural and non-damaging conditions. It can be obtained from leaves (senna), middle lamella (aloe), etc., in addition to woody parts and seed coating(Beikzadeh et al., 2020). It is a heteropolysaccharide, more readily forming sticky masses with water, i.e. absorbing water and swelling but not dissolving, insoluble in organic solvents. It is abundant in cactus (and other succulent plants) and flaxseed.

Mucilage can be derived from a wide variety of plants and their composition and function vary. *Opuntia ficus-indica* mucilage can be used to improve the quality of breba figs by effectively maintaining the fresh weight of the fruit, maintaining visual value, fruit firmness and total carotene content, and also significantly reducing the development of enterobacteria(Allegra et al., 2017). Shirazi balangu (*Lallemantia royleana*) seed mucilage can be used to extend the shelf life of beef (at 4 ℃) to prevent lipid oxidation and microbial spoilage(Behbahani & Imani Fooladi, 2018).

3.2. Lipid

Lipid-based materials including Waxes and paraffin(Paraffin wax, Carnauba wax, Beeswax, Candelilla wax), Acetoglyceride, Resins(Shellac resins, Propolis), Fatty acid (Palm oil, Coconut oil). Lipids are hydrophobic, which means they could act as excellent barriers to water transmission. They can protect the wrapped food against abrasion during transportation, and apply a shiny and aesthetically pleasing appearance. Lipids can slow down or completely prevent gas migration, thus affecting the gas transportation. On the other hand, which may lead to unwanted physiological processes, such as anaerobic respiration. As a result, product quality degradation, tissue structure softening, flavor alteration, ripening, promotion of microbial reactions, or susceptibility to oxidative spoilage of foods may occur. In addition, applying these lipids to wet surfaces would be difficult because of the weak adhesion at the film-food interface. However, dual-coating and emulsions - mixtures of lipids and carbohydrate components emulsified by proteins - are possible solutions to avoid the above mentioned flaw(Brychcy-Rajska, 2017; Dhaka & Upadhyay, 2018).

3.2.1. Waxes and paraffin

Waxes are a class of heterogeneous lipids containing hydrocarbons and other non-polar substances. Natural waxes can be of plant, animal or mineral origin. Waxes of animal and plant origin are mixtures of long-chain fatty acids, fatty alcohol esters and hydrocarbons; those of mineral origin consist mainly of paraffinic hydrocarbons(Bucio et al., 2021). Waxes are found in nature as coatings on leaves and stems, and therefore were used early on as edible film materials, first applied to citrus fruits(El Assimi et al., 2020).

Waxes and paraffins can block moisture (providing the greatest moisture barrier) and also improve surface appearance (providing a shiny attractive look). When coated in a thick layer, they should be disposed of before ingestion (e.g. cheese); however, when coated in a thin layer, they are considered fit to be directly edible. These waxes are effective food films as well as being healthy and safe edible compounds. Coatings and films based on waxes and paraffins are commonly used for cheeses, uncooked fruits and vegetables.

3.2.1.1. Paraffin wax

Paraffin wax can be extracted from crude oil by fractional distillation. Paraffin waxes consist of smaller molecules and have a lower melting point than regular waxes(Molefi et al., 2010). Thus, paraffin waxes have good burning properties and they are effective in blocking moisture. Ordinary waxes are tougher and more flexible than paraffin waxes, and they are more viscous.

Paraffin wax can be mixed with other waxes for cheese to protect it from external forces with a low tendency to fracture and to reduce water vapor permeability(Bucio et al., 2021).

3.2.1.2. Carnauba wax

Carnauba wax is derived from Copoernica Cerifera (palm leaves). Can be used for apples to block water vapor and reduce weight loss(Chiumarelli & Hubinger, 2012). Or mixed with proteins and carbohydrates for walnuts and pine nuts to prevent oxidation and hydrolytic rancidity and to improve smoothness, flavor and overall appearance(Mehyar et al., 2012).

3.2.1.3. Beeswax

Beeswax comes from honeybees. Beeswax coatings with glycerol additives can be used for dry sausages to reduce weight loss(Hassan et al., 2018).

3.2.1.4. Candelilla wax

Candelilla wax comes from the candelabra plant. Can be used on fruits, such as strawberries, to improve post-harvest shelf life through its anti-fungal properties. Or guava fruit, to extend shelf life, reduce weight loss and ethylene emission, and limit softening and hardness loss, while giving the fruit a good gloss and maintaining color(Tomás et al., 2005). Or apples, to maintain their good organoleptic qualities, reduce weight loss, and inhibit fungal strains and microbial activity(Ochoa et al., 2011). It can also be applied to vegetables, such as broccoli florets, which can reduces weight loss, retains vitamin C and polyphenols, limits softening during storage, and improves overall appearance(Kowalczyk et al., 2010).

3.2.2. Acetoglyceride

Acetoglyceride generally refers to acetylated monoglycerides, which are 1-stearic acid glycerides produced by the reaction of acetic anhydride with acetylated monoglycerides. Acetylated monoglycerides can be easily solidified from a molten state to a pliable strength like a wax. It has excellent ductility and low vapor permeability compared to polysaccharide materials. It has very low permeability to oxygen and therefore may cause discoloration of meat. It is commonly applied to chicken and meat fillets to inhibit moisture loss during storage.

Acetoglyceride can be used in meat products and exhibits excellent water retention capacity(Lin & Zhao, 2007; YB & Manjula, 2019).

3.2.3. Resins

Resins are secreted by plants as a response to protect them under injured conditions. The resin can protect the plant from insects and pathogens. Most plant resins consist of terpenes, and some resins also contain a high percentage of resinous acids.

3.2.3.1. Shellac resins

Shellac resins are derived from the secretions of Laccifer lacca (insect). It creates an additional gloss on the food surface. Acts as a gas barrier, giving the product less internal O_2, better internal CO_2 and greater ethanol content substance, high ethanol content can affect the taste of the food. It is usually applied on fruits. However, shellac resins are not recognized as safe (GRAS) substances and are only approved as auxiliary chemicals in edible coatings. They are mainly used in the pharmaceutical sector and rarely in the food sector.

Shellac can be applied to the surface of the nuts to prevent oxidation and water transfer between components with different water activity(Pérez-Gago & Rhim, 2014).

3.2.3.2. Propolis

Propolis, also known as bee glue, is a natural resin collected by worker bees from the mucilage, gums and resins of several plants (trees and flowers). Propolis is used by bees to mix it with wax to build and maintain their hives. The difference between beeswax and propolis is that beeswax is a secretion produced by bees, while propolis is collected by bees from plants. The functional properties of propolis are closely related to its type and geographical origin(Yong & Liu, 2021).

The main properties of propolis are its excellent antioxidant and antibacterial properties, its use in raspberry fruit as an antifungal agent, and its ability to improve the mechanical properties of protein membranes - enhancing elasticity and stretchability(Moreno et al., 2020). It has also been shown to give strawberries higher levels of total phenolics, flavonoids and antioxidant capacity after storage without altering sensory properties(Martínez-González et al., 2020). The treated figs maintained their normal ripening process during 12 days of storage with reduced weight loss, in addition to increased antioxidant capacity, fungal inhibition, and a significant reduction in aflatoxin production(Aparicio-García et al., 2021).

3.2.4. Fatty acid

Fatty acids are carboxylic acids with long fat chains, which are classified as saturated or unsaturated. They are commonly used as modifiers in edible food films to improve their mechanical properties, such as moisture permeability, oxygen permeability, elongation strength, etc. It is rarely used as a base material because it is more difficult to be shaped.

3.2.4.1. Palm oil

Palm oil comes from the fruit of the oil palm tree, which has a high melting point and therefore low plasticity, which can be resolved by blending with other oils with lower melting points, or by hydrogenation, esterification and fractional distillation(Subroto & Nurannisa, 2021).

Palm oil and tapioca starch mixed with gelling agents can be used in eggs, extending their shelf life and reducing weight loss due to their high compatibility and water resistance(Homsaard et al., n.d.).

3.2.4.2. Coconut oil

Coconut oil comes from the coconut tree (Cocos nucifera) and is obtained by pressing the flesh of fresh or dried coconut meat called copra, which can achieve anti-aging effect by controlling respiration rate, transpiration rate and ethylene biosynthesis process.

Mixing coconut oil and protein improves oxidative stability(Carpiné et al., 2015). Mixing with wax keeps lemons green, reduces respiration, ethylene production, weight loss and shriveling, and maintains firmness and moisture content(Nasrin et al., 2020).

3.3. Protein

Protein-based materials include collagen, casein, gelatin, quinoa protein, whey protein, corn protein, wheat gluten, egg white protein, myofibrillar protein, soy protein, and keratin. Most protein materials are actually a mixture of various proteins. It is important to note that certain proteins may cause allergies (e.g. wheat proteins). The physical stability of protein materials makes them easy to maintain the desired form, but it has poor physical properties, such as tensile strength, elongation at break, and puncture strength. Also, they are difficult to act as moisture barriers and do not adequately control the transfer of O_2, CO_2 and other gases. In addition, the permeability of the films depends mainly on the protein composition, with lower molecular weight components exhibiting higher permeability but usually being more soluble. This limitation can be offset by cross-linking, but edibility and mouthfeel may be compromised by this treatment. Cross-linking can occur in proteins, and its isoelectric point depends on the interaction of the amino and carboxyl groups of the protein. Protein materials form edible coatings and films with significantly different properties (e.g., color, texture, tensile strength) depending, in addition to the material, on the pH of the solution in which the film/coating is cast.(Brychcy-Rajska, 2017; Dhaka & Upadhyay, 2018; García et al., 2002)

3.3.1. Corn zein

Zein is a group of alcohol-soluble proteins (proproteins) found in corn germ that possess good film-forming properties and can act as a good moisture barrier. Plasticizers are added to synthetic zein films and coatings to produce better elasticity to balance the highly brittle nature of the zein proteins. Fatty acids or cross-linking agents can also be used to improve the water vapor barrier properties of zein films and coatings. Zein is aqueous because of the high content of non-polar amino acids and is soluble in 70-80% ethanol.

Zein protein is used to fortify rice with vitamins and minerals to prevent loss of vitamins and minerals during cold water washing(Padua & Wang, 2002). It is also used in nuts to prevent oxidation of oils(Colzato et al., 2011).

3.3.2. Gelatin

Gelatin, which can be obtained from fish. Gelatin exhibits good transparency, mechanical and barrier properties and can be manufactured by extrusion or casting processes. Gelatin is effective in blocking O_2 and aromatic odors at low or medium relative humidity (RH). gelatin is hydrophilic and therefore less resistant to water and is soluble in polar solvents such as hot water, glycerin and acetic acid, but insoluble in organic solvents such as alcohol. Moreover, gelatin will absorb water and swell at lower temperatures without dissolving, however, after heating, the swollen gelatin will dissolve easily and form a viscous solution. The mechanical properties are closely related to its degree of re-saturation. Gelatin is commonly used in the pharmaceutical industry and for encapsulating oil-based foods.

Gelatin can be used to protect meat products, such as dry-heated smoked sausages, by reducing the weight loss of the product(Tyburcy & Kozyra, 2010).

3.3.3. Collagen

Collagen is an abundant protein component of vertebrate and invertebrate connective tissues (cartilage, bone, tendons, ligaments, skin, etc.). Collagen has a good barrier to oxygen, probably due to their impermeability to polar substances and the high value of cohesive energy they contain. collagen is insoluble in water, but lowering the pH of the solution increases its solubility. And when placed in boiling water, collagen is converted to gelatin.

Collagen can be used to protect mangoes and apples by reducing the rate of gas transfer and thus extending their shelf life(Lima et al., 2010).

3.3.4. Wheat gluten

Wheat gluten, the storage protein in wheat, with unique viscoelastic and adhesive properties. Wheat gluten is composed of two main proteins: the glutenins and the gliadins. They are both insoluble in water, but gliadin is an alcohol-soluble protein. The purity of the protein has a great influence on the appearance and mechanical properties of the coatings and films. Higher purity gluten results in more stable and clearer films. Plasticizers and glycerin can be used to improve flexibility. Sorbitol can also enhance flexibility, but can result in reduced elasticity and moisture resistance. The use of cross-linking agents can improve tensile strength. It is also important to mention that gluten may cause allergies.

Gluten have been used to maintain the sensory attributes and physical-biochemical quality of trout fillets(Kilincceker et al., 2009).

3.3.5. Egg white/albumen protein

Egg white/albumen protein comes from egg white, the clear liquid contained in eggs (also called albumin or enamel/enamel). This material is resistant to breakage, heat and oxygen, and exhibits good transparency, brightness and color, and is water soluble. In addition, it has antibacterial and antiviral effects , especially in relation to lysozyme. After heating above 60℃-80℃will lead to denaturation.

Egg white proteins can be used to protect edible oils, effectively delaying oil rancidity during storage(X. Huang et al., 2020).

3.3.6. Whey protein

Whey is a by-product of cheese making and casein manufacturing in the dairy industry and is the aqueous portion of milk separated from the curd during the cheese making process. It has top film-forming ability and is commonly used in infant formulas and physical activity foods. It can be used as a mechanical barrier, with the good gas barrier properties at low relative humidity, and good barrier properties to aromatic compounds and oils. Compared to synthetic polymer films, it exhibits good mechanical properties, as well as moderate moisture permeability and good oxygen barrier properties. What's more, due to some limitations of its hydrophilicity, lipids were usually added to improve its water barrier properties.

Whey protein can be used in meat and fish products, such as Atlantic salmon(Rodriguez-Turienzo et al., 2012) or chicken breast fillets(Fernández-Pan et al., 2014) to improve quality, extend their shelf life, and have some antimicrobial effects.

3.3.7. Caseins

Caseins are derived from mammalian milk and account for approximately 80% of the protein in cow's milk and have some hydrophobicity. It can form films that are stable at different pH values, temperatures and salinities. In particular, the films produced from β-casein are less permeable to water vapor than other milk proteins. Caseinate is a mixture of casein monomer and small aggregates formed after removal of colloidal calcium phosphate from casein micelles. Caseinate, especially sodium caseinate, is more soluble and has better film-forming ability than casein. Films produced from sodium caseinate have excellent barrier to O_2, CO_2 and aromas and are heat resistant. Edible caseinate coatings and films can be prepared by drying aqueous caseinate solutions.

Caseinate based coatings have been used to protect the microbial levels of ground beef(Lacroix et al., 2004). Extend the shelf life of partially dehydrated pineapple(Talens et al., 2012) and maintain the phytochemical content of berry cactus(Correa-Betanzo et al., 2011).

3.3.8. Quinoa protein

Quinoa protein is derived from quinoa. Quinoa proteins have good mechanical properties as well as good ductility. However, its water vapor barrier property is poor and can be improved by cross-linking with transglutaminase.

Quinoa protein can help reduce the weight loss of frozen strawberries without changing quality parameters (pH, titratable acidity and percentage of soluble solids), thus extending shelf life(Robledo et al., 2018).

3.3.9. Myofibrillar protein

Myofibrillar proteins are mainly derived from meat, fish, contain high molecular weight crosslinks that form complex film networks, presenting low solubility and requires high concentrations of salt (>0.3 M) to dissolve. It blocks UV light very well. The thickness, color properties and transparency of the formed film can be similar to those of PVC films. The protein concentration has a strong influence on its properties.

3.3.10. Pea protein

Pea protein is a powdered, concentrated protein substance (aka pea protein isolate) that is removed from peas to leave the starch and fiber. It is water-soluble, but virtually insoluble at pH 5.0 (near the isoelectric point). This protein shows poor lubricity at higher concentrations, which may lead to an unpleasant taste. However, it has good surface activity, acts as an emulsifier, and also exhibits some antioxidant activity, but much weaker than conventional antioxidants.

Pea isolate can be applied to grapes to maintain their high ascorbic acid, reducing sugar content, reducing weight loss, keeping them fresher for longer and also giving the fruit an attractive glossy surface(Kowalczyk & Pikula, 2010).

3.3.11. Soy protein

Soy protein comes from soybeans and is made from soybean meal that has been hulled and defatted. It is soluble in water and almost insoluble at pH 5.0 (near isoelectric point). At low relative humidity, the O_2 permeability of soy protein isolate films was lower than that of films based on polysaccharides. The films often have a faint soy flavor, are brittle, and have relatively poor mechanical properties. These properties can be modified by physical, chemical or enzymatic treatment, or improved by blending with starch, sodium alginate, whey protein separation, etc.

Soy protein as an edible coating can be used to extend the shelf life of fresh-cut apples(Alves et al., 2017). Or reduce the weight loss of apricots (stored at 2 ℃) and maintain mass by inhibiting the degradation of pectin(L. Zhang et al., 2018).

3.3.12. Keratin

Keratin, generally referred to as alpha-keratin, is a keratin protein in vertebrates and is the structural material that makes up the scales, hair, nails, feathers, horns, claws, hooves, and outer layer of skin in vertebrates. Keratin is the major structural fiber and insoluble protein found in chicken feathers. Keratin is insoluble in water and has high mechanical strength(Das et al., 2018). The number of disulfide bonds largely determines whether the keratin material is soft, flexible and stretchable (low content) or hard, tough and inextensible (high content).

Keratin mixed with carbohydrates improves mechanical properties, such as tensile strength and surface smoothness, and exhibits proper stability in water(Oluba et al., 2021). When applied to cover fried fish fillets, it can reduce weight loss, lower hardness values, and reduce the number of microorganisms on the surface(Das et al., 2018).

3.4. Composite Materials

Edible films and coatings produced from only one type of natural film-forming biopolymer provide both, advantages and disadvantage. Therefore, most studies focus on blending several polymers or incorporation of different components in order to obtain edible materials with appropriate functional properties. Composite edible films and coatings are developed by the use of more than one ingredient mentioned above, which could take advantage from synergistic reactions between them. **Table 1** shows the composite materials prepared and used for edible coatings or films.

Table 1. Composite materials feature and applications

Composites Type	Applications (Materials)	Products & Effects	Refs
Polysaccharides+ Lipid	Emulsified edible coatings composed of corn starch, MC, and soybean oil	Coated crackers: Extended the shelf life, stored at 65%, 75%, and 85% RH compared to uncoated ones by reducing moisture uptake	(Hassan et al., 2018)
Polysaccharides+ Protein+Lipid	Whey protein isolate (WPI), pea starch (PS), and their combinations with carnauba wax (CW)	Walnuts and pine nuts: Reduced the oxidative and hydrolytic rancidity of the nuts and improved sensory characteristics.	(Mehyar et al., 2012)
Polysaccharides+ Protein+Lipid	Carrageenan and whey protein coatings with CMC sodium salt, polyethylene glycol, calcium chloride, glycerol and oxalic acid additives	Minimally processed apple slices: Applied as semipermeable barriers against air. Combined with anti-browning agents, effectively prolonged the shelf-life. Addition of $CaCl_2$ (1 g/100 mL) significantly inhibited the loss of firmness. Shows positive sensory analysis results and beneficial reduction of microbial levels.	(Lee et al., 2003)
Polysaccharides+ Polysaccharides	Sodium alginate and pectin coatings with calcium chloride, ascorbic acid, sodium chlorite additives	Fresh cut apple: Flavonoid and phenolic content, sugar and sweetness index, sensory qualities microbial and ethylene production.	(Guerreiro et al., 2017)
Polysaccharides+ Polysaccharides	Cassava starch and chitosan with myrcia ovata cambessedes essential oils, acetic acid and glycerol additives	Mangaba fruits: Controlling foodborne bacteria and natural microorganism growth during the storage.	(Frazão et al., 2017)
Polysaccharides+ Polysaccharides	Chitosan and gelatin coatings	Red bell peppers: Enhanced fruit texture and prolonged the possible period of cold storage up to 21 days and fruit shelf-life up to 14 days, without affecting the respiration or nutritional content.	(Poverenov et al., 2014)
Polysaccharides+ Protein	Starch based (potato, maize, and rice resistant starches) coatings with D-mannose, maltodextrin, and whey protein concentrate	Spray-dried microencapsulation of Lactobacillus acidophilus: Enhance the longevity of probiotics at high temperatures of spray-drying process, storage, and targeted delivery in the gastrointestinal tract.	(Muhammad et al., 2021)

Polysaccharides+ Protein	Protein and the gum of Cajanus cajan seeds	Strawberries: Against water vapor transfer, without color changes and attractive mechanical properties. Delay the ripening of strawberry fruit, reduce the undesirable dehydration, and increase the shelf life during refrigerated storage, without losing its sensory attributes.	(Robles-Flores et al., 2018)

3.5. Agro-industrial Residues/Wastes

The food and food ingredient industrial production are associated with the generation of large amount and unavoidable by-products and waste. In 2011, FAO presented the estimate that around 1/3 of the world's food was lost or wasted every year. Since then, food loss and waste has become an issue of great public concern. The 2030 Agenda for Sustainable Development reflects the increased global awareness of the problem. The Food Loss Index (FLI), prepared by FAO, tells us that around 14 percent of the world's food is lost from post-harvest up to, but excluding, the retail level.(*Food Loss and Food Waste | FAO | Food and Agriculture Organization of the United Nations*, n.d.; Tassoni et al., 2020)

Agro-industrial residues/wastes mainly come from: Fruit and vegetable residues (peel, pomace, seed); Wine manufacture wastes; Sugarcane bagasse.(Galus et al., 2020) Despite the wide commercial spectrum of biodegradable coatings and films production increase, some restrictions such as relatively less research, material limitations, higher requirements for processing technology and cost, in comparison to those of conventional materials, are yet to be overcome. For instance, biodegradable films/coatings from agro-industrial residues/wastes, mainly based on starch and fruit purees (mainly are polysaccharides), show high permeability to water vapor and low mechanical properties, thus need using plasticizers and reinforcing materials. However, many of these reinforcing materials result in poor adhesion at the interface with other matrix components.(Brito et al., 2019) The examples of agro-industrial residues/wastes materials, applications and effects as edible coatings or films are listed in **Table 2**.

Table 2. Agro-industrial residues/wastes materials, applications and effects

Materials	Applications and Effects	Refs
Apple puree with various concentrations of fatty acids, fatty alcohols, beeswax, and vegetable oil	Fresh cut apple pieces: Extend the shelf life and improve the quality	(McHugh & Senesi, 2000)
Hydroxyethyl cellulose and sodium alginate edible coating containing **asparagus waste extract**	Strawberry fruit: Display a continuous, smooth and porous structure. Exhibite favorable anti-fungal activity against Penicillium italicum. Delay color change, reduce weight loss, and maintaine total phenolic and flavonoid contents.	(Liu et al., 2021)

Keratin extracted from **chicken feather waste** and starch extracted from turmeric	The addition to starch-composite showed improvement in mechanical properties (tensile strength and surface smoothness), exhibited appropriate stability in water.	(Oluba et al., 2021)
Chicken bone gelatine and cinnamon bark oil	Mozzarella cheese: Wrapping mozzarella cheese inoculated with Listeria monocytogenes, the population of the bacterium decreased after 20 days in storage (improve the microbiological safety), also increases the tensile strength and increases water solubility, decreases elongation at break.	(Kim et al., 2018)
Fabrication of silk nanodisc (SND) dispersed chitosan (CS)Fabrication of SND is attained following acid hydrolysis of silk fibroin (SF), the SF has been fabricated from **waste muga cocoons** using the degumming process.	Banana fruits: Improve the shelf life of bananas over 7 days at 25 °C for prevailing original weight, optical property, firmness, and others. Also with superior thermal, hydrophobic, optical, mechanical, and physicochemical properties.	(Ghosh et al., 2021)
Banana flour, glycerol (Gly) and pectin	Flexible, transparent and slight yellowish appearances. Presents sealability, which allows the formation of sachets to pack powder ingredients like sugar, maintaining quality. Used for dried foods, instant water-soluble ingredients or applied as a wrap or coating on food products.	(Sothornvit & Pitak, 2007)
Banana peel flour with cornstarch	High permeability to water vapor, being dependent on the starch concentration. Low tensile strength, influenced by the starch concentration, and by the low thickness and filmogenic composition	(Arquelau et al., 2019)
Carrot puree, chitosan, corn starch, gelatin, glycerol and cinnamaldehyde	Fresh-cut carrots: Delay the senescence, reduce the deterioration of exterior quality and retaine total carotenoids, inhibit polyphenol oxidase (PPO) and peroxidase (POD) activity, reduce accumulation of polyphenols	(Wang et al., 2015)
Papaya puree with alginate, glycerol, and citric acid	Minimally processed products with compatible colors (pumpkin, carrot, persimmon, and tangerine slices): Extend the shelf life, also will not change the product flavor.	(Rangel-Marrón et al., 2019)
Pomelo peel flour (PFP) with tea polyphenol (TP)	Good film-forming substrate, and TP improve antioxidant and antimicrobial activity as well as mechanical and water-barrier properties. 10% TP had relatively excellent combination properties due to the stronger intermolecular interactions and more compact microstructure.	(H. Wu et al., 2019)
Guinea arrowroot starch and **wastes from wine manufacture**, plasticized with glycerol	Edible and pH-sensitive films: indicated by anthocyanins contained in grape wastes	(Gutiérrez et al., 2018)
Lentil flour, residue of a commercial lentil protein extraction process	Act as reinforcement for starch films: Strength at break, and toughness of the composites, and decreases in water vapor permeability, thermally stable up to 240 °C.	(Ochoa-Yepes et al., 2018)
Pomegranate peel extract with sodium caseinate	Ground meat: Extend the shelf life. Act as antimicrobial agent and increase the water vapour permeability.	(Emam-Djomeh et

	Antimicrobial effectiveness of prepared films was more pronounced against Gram-positive strain compared with Gram-negative strain.	al., 2015)
Cellulose nanocrystals from sugarcane bagasse on whey protein isolate-based films	The film became more hydrophilic when the cellulose nanocrystal was added. The addition of CNCs increase the tensile strength and Young's modulus and reduce the water vapor permeability of WPI-based CNC films. However, the CNCs did not change the oxygen permeability of the film. Therefore, the obtained WPI films provided good mechanical performance.	(Sukyai et al., 2018)
Cocoa pod husk cellulose incorporated with **sugarcane bagasse fibre**	Reduce the possibility of mould growth on the bioplastic surface and could prevent the moisture transfer.	(Azmin et al., 2020)
Brewer's spent grain protein, prepared by casting protein dispersions at different pH values, plasticizers [polyethylene glycol (PEG) or glycerol] and PEG	Higher PEG concentrations increase water solubility, water vapor permeability and elongation at break, and decrease tensile strength and elastic modulus. Antioxidant activity depends on PEG concentration, whereas no antimicrobial properties against Bacillus cereus, Salmonella newport and Penicillium corylophylum were detected.	(Proaño et al., 2020)

4. Additives

Additives can be used to improve the quality of the food being wrapped (e.g. enhance color, flavor or appearance), provide added value (e.g. add nutrients), extend its shelf life (e.g. add antioxidants or antimicrobials).

4.1. Antimicrobials/Preservatives and Drugs

The antimicrobials can be obtained from two main resources including natural resources and chemical synthetic resources. For natural resources there are three main sources: First, plant sources: essential oils (cinnamon, oregano, rosemary, and lemongrass) and plant extracts (polyphenols: flavonoids and phenolic derivatives); Second, microbial sources: bacteriocin (lysozyme and nisin) and organic acids (sorbic and its potassium salt, acetic acid, and malic acid); Third, animal sources: chitosan, enzymes and antioxidant peptides.(Baptista et al., 2020; Hussain et al., 2021) For chemical synthetic resources: including parabens, potassium and calcium sorbate/sorbic, ethylene diamine tetraacetic acid (EDTA), benzoic acid and sodium benzoate etc.(Dhaka & Upadhyay, 2018)

Its worthy to mention that, besides of natural antimicrobials agents, food corruption and spoilage caused by food-borne pathogens and microorganisms can also be addressed by antimicrobial drugs. Compared with natural antibacterial agents, antimicrobial drugs have the advantages of low cost and high activity, but their toxicity is usually higher. Therefore, the design and synthesis of antimicrobial drugs with highly effective, less toxic, and no adverse effects on the taste and appearance of food is an important research topic(T. Huang et al., 2019; Lacroix & Vu, 2014).

4.2. Antioxidant

Antioxidants are capable of delaying, retarding or preventing the onset of food rancidity or other taste deterioration due to oxidation, such as oxidative rancidity, degradation and discoloration (enzymatic browning) of certain foods. These include ascorbic acid (Vc), citric acid, oxalic acid, tocopherols, plant extracts and essential oils (EO), or their components.(Galus & Kadzińska, 2015; Ganiari et al., 2017)

4.3. Colorants

Food colorants are chemical substances added to food matrices to enhance or maintain the color appearance of foods, properties that may be affected or lost during processing or storage. These classifications are based on the following: First, whether they are natural or, if synthetic, organic or inorganic. Second, based on their solubility (e.g., soluble or insoluble) or covering ability (e.g., transparent or opaque)(Ntrallou et al., 2020). Natural colorants are the current trend to replace synthetic colorants because they may have other health benefits(Sigurdson et al., 2017), but naturally derived colorants are usually less stable to heat, light, and oxygen, colors are often less vibrant, and may interact with other ingredients, resulting in unwanted colors and flavors(Wrolstad & Culver, 2012). Natural colorants include anthocyanins, carotenoids, beet colorants, phenolic compounds, annatto, carminic acid, and curcumin etc.

4.4. Flavors and Fragrances

Flavors and fragrances are compounds mainly to ameliorate the olfactory and gustatory sensations of the product. They comprise both synthetic and naturally occurring molecules, such as essential oils (EO) and aroma compounds. Especially those of natural origin, which are mostly derived from plants, possess, in addition to sensory properties, also various biological activities (e.g., antibacterial, antiviral, antifungal, antiprotozoal, insect-repellent, anticancer, anti-inflammatory and antioxidant)(Dosoky & Setzer, 2018). The major drawbacks regarding their use are related to the volatility and chemical instability, since most of these compounds are sensitive to light, heat or oxygen(Braga et al., 2018). These concerns can be solved when encapsulated(Perinelli et al., 2020).

4.5. Nutrient Content

Adding nutrient content is another way of food fortification or enrichment, which means adding micronutrients (essential trace elements and vitamins) to food products. Food coatings can be excellent carriers of nutrients, enhancing the nutritional value of fruits and vegetables by carrying nutrients or nutraceuticals that are lacking or present in small amounts(Zhao & McDaniel, 2005). For instance, incorporating high concentrations of minerals or vitamins into chitosan-based films(Han et al., 2004; Park & Zhao, 2004) and adding calcium and vitamin E to milk protein-based films(Mei & Zhao, 2003).

4.6. Probiotics

Probiotics are live, non-pathogenic microorganisms used to improve microbial balance, especially in the gastrointestinal tract. Probiotics exert their beneficial effects through a variety of mechanisms, including lowering intestinal pH, reducing colonization and invasion by pathogenic organisms, and altering the host immune response(El-Sayed et al., 2021; Williams, 2010).

Food coatings containing probiotics have shown health benefits in addition to their basic characteristics. In addition, since probiotic microorganisms usually have an inhibitory effect on spoilage or disease-causing bacteria, their inclusion can also improve the stability and safety of food products. More importantly, foods coated with a certain concentration of probiotics can be considered as the functional foods. The material used to incorporate the probiotic bacteria has a significant impact on the antimicrobial activity of the probiotic strain. The modulation of this activity can be correlated with the permeability of the coating to the antimicrobial metabolites produced by the probiotic cells and the ability of the material to protect the active cells(Pop et al., 2020).

5. Characterization

The microstructural characteristics of edible coatings and films (e.g., chemistry, crystal structure, and morphology) are closely related to their packaging properties (e.g., mechanical properties, barrier properties, thermal properties, sensory and textural properties, optical and color properties, and other properties). In this section the measurement of these properties will be briefly described.

5.1. Structural Properties

The structural characteristics can be used to determine the packaging properties or to find ways to improve them. There are several methods for structural analysis of the edible coating and films. In order to analysis the functional chemical groups, conformational transitions and molecular interactions, Fourier Transform Infrared Spectroscopy (FTIR) is the first method to be used. Another useful method is nuclear magnetic resonance (NMR) spectroscopy. Using NMR technique, we can analyze the chemical and physical properties of the atoms or their associated molecules as well as reaction states, dynamics, structure and chemical environment. One of the most common methods for study the structure and architecture of hydrocolloid-based films and coatings at the micron and nanoscale is microscopy techniques such as confocal laser scanning microscopy (CSLM), scanning electron microscopy (SEM) and atomic force microscopy (AFM). CLSM can characterize ultra-structures and internal structures in thin films. While the SEM and AFM are used for studying the surface and cross-sectional morphology (Xiao, 2021).

5.2. Mechanical Properties

Mechanical properties can determine whether the coating or film can be formed and whether it can effectively wrap the contents. Generally, the standard method for evaluation of mechanical properties such as tensile strength, elongation at break, elastic modulus, and toughness is ASTM D882. The mechanical properties can be calculated by determination of the relationship between stress and strain during the stretching of the film with specific rate. Tensile strength (Eq. 1) is the maximum strength that the film can withstand when being stretch or another word is the maximum point of stress versus strain. The stretching capacity of flexibility of the film prior to breaking is known as elongation at break. Eq. 2 shows the elongation at break in which L_0 is the initial length, and L is the length of the film at breaking point. Elastic modulus is the slope of the linear range of the stress–strain curve which can be defined as the intrinsic film stiffness. Finally, the area under the stress-strain curve is known as the toughness. Toughness is the materials ability to gain energy during deformation up to the failure (Xiao, 2021).

$$\text{Tensile Strength (MPa)} = F/A = \frac{\text{Force at maximun load (N)}}{\text{The initial cross sectional area (m}^2\text{)}} \quad (1)$$

$$\text{Elongation at break (\%)} = (L-L_0)/L_0 * 100 \quad (2)$$

5.3. Barrier Properties

Barrier properties are used to assess water vapor and gas permeability, whether the exchange of water vapor and gas between the food and the external environment can be effectively controlled [8]. Generally, the water vapor permeability is evaluated using ASTM E96-95. Briefly, the permeation vial cells with a depth of 2.5 cm and entrance diameter of 1cm will be covered with the films or the coating. The vials were placed in desiccators containing a saturated salt solution such as magnesium nitrate with a constant relative humidity (RH) of 52% at 25 °C. The weight loss of the cells due to water evaporation was measured every 24 h, with the change recorded as a function of time and calculated using Eq. 3. This equation is based on the water vapor transmission rate (WVTR $g \cdot m^{-1} \cdot h^{-1} \cdot Pa^{-1}$), calculated from the slope of the straight line divided by the exposed film area (m^2); R_1 and R_2: the relative humidity (RH) in the desiccator and the vial, respectively; P: the saturation vapor pressure of water (Pa) at 25°C (3.173 kPa). It is important to note that WVP is influenced by the thickness of films(Davoodi et al., 2020).

$$WVP = WVTR/P(R_1-R_2) \quad (3)$$

Gas Permeability/Oxygen permeability (O_2P) and carbon dioxide permeability (CO_2P): Measured by O_2/CO_2 sensors or quantification by gas chromatograph using ASTM D1434(Hosseini et al., 2013).

5.4. Thermal Properties

Thermal properties are used to determine the processing conditions and to clarify its stability under heating conditions. There are three methods for assessment of the thermal properties of the films and coatings which are differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), and dynamic mechanical analysis (DMTA). DSC technique is used to determine the glass transition temperature (T_g), melting temperature (T_m), crystallization or decomposition temperature (T_c), heat capacity difference at T_g and the enthalpy of crystallization (ΔH_c) according to ASTM D3418. TGA widely employed to examine their decomposition temperature, weight loss, and activation energy of decomposition according to ASTM E1131. Finally, DMTA investigates the structural and viscoelastic properties of the films according to ASTM D4065. Forced oscillation method: the functions of temperature and frequency, used to measure dynamic modulus, dynamic loss modulus, temperature of main chain relaxation, and temperature of local mode relaxation(Davoodi et al., 2020; Xiao, 2021)**.**

5.5. Sensory and Texture Properties

Sensory and textural properties help assess whether coatings and films can affect product quality by introducing undesired sensory properties such as taste, color, and odor. Sensory properties of food materials including appearance, texture, aroma, taste, and irritation. These are perceived by the primary human senses—visual (sight), tactile (touch), olfactory (smell), gustatory (taste), auditory (hearing), and chemesthesis (common chemical sense). These properties usually analyzed by sensory evaluation tests designed, subjects can be professional laboratory staff or potential consumers (*Probing the Sensory Properties of Food Materials with Nuclear Magnetic Resonance Spectroscopy and Imaging | SpringerLink*, n.d.).

Texture properties such as hardness, cohesiveness, and chewiness, can be described as "hard/soft"," liquid/solid", "rough/smooth", "creamy/crispy" and etc. The properties can be analyzed by texture measurements, which is based on stress-strain relationships (Mechanical Properties) or rheological properties (Cao et al., 2020; Hofmanová et al., 2019).

5.6. Optical and Color Properties

Optical and color properties are one of the main properties as they are the first thing the consumer will see them. These properties are checking the transparency and determine the effect on product appearance. In optical properties (Light transmission and transparency), the barrier properties of films against ultraviolet (UV) and visible light were measured at selected wavelength between 200 and 800 nm, measured by UV-visible spectrophotometer(Davoodi et al., 2020).

The color characteristics of the films usually measured using a chroma meter which is calibrated by a white plate background to prevent unprecise data. The chroma meter normally gives three values, which are the reflected light from the film or coating surfaces (CIELAB values). These values are a^* (redness+ or greenness-), and b^* (yellowness+ or blueness-) and L^* (lightness) (Davachi et al., 2021).

5.7. Other Properties

Moisture content, water solubility and activity of the films and coatings are also very important to determine the method of processing or application conditions. While the surface behavior needs to be considered to examine the hydrophilicity or hydrophobicity of the coating and films(Davachi et al., 2021). The water activity of the films and coatings will be measured using water activity meter, in triplicates for ~5 min each with the mean temperature of 25 °C.

The moisture content of the films which is the empty volume in the film's microstructure network filled by water molecules was calculated according to the ASTM D4442 method. Films were dried in an oven at 103±2 °C and their mass change was monitored until a constant weight was obtained.

The water solubility of the films was determined by the ratio of the weighed round-shaped (1×1 cm^2) dry films after immersion in 50 mL of MQ water under constant stirring at 25 °C for 5 h. Then, the films were removed and dried at 100 ± 2 °C until no more change in weight was observed (final dry weight). The solubility percentage (triplicates for each film) was measured using Eq. 4.

$$\% \text{ Solubility} = \frac{[\text{Initial dry weight}]-[\text{Final dry weight}]}{[\text{Initial dry weight}]} \times 100 \quad (4)$$

Finally, to examine the surface behavior of the films and coatings contact angle measurement will be performed. In this method depending on the nature of the surface a small drop of a specific liquid such as MQ water or diiodomethane (DIM) will be deposited on the surface and the angle between the surface of the film or coating automatically will be measured

6. Conclusion and Future Trends

Various researches have been written about edible food coatings and films, however, the main purpose of the coatings never changes: to protect foods and prolong their shelf-life without damage their sensory attributes and nutrition values. The basic material is the main factor that determines the characterizations and functional properties of edible coatings, which also affected by the combined proportions, producing method, and additives. Agro-industrial residues/wastes are materials that are easy access and resourceful, low-cost, and with abundant nutrients. Using these materials have the benefits of reducing food waste, being environmentally friendly, contributing to sustainability, being economical, and possibly providing some extra health benefits. Therefore, besides reaching the basic goal of applying edible films and coatings, more researches about agro-industrial residues/wastes - with the aim of benefits human health, global economics and the environment - are needed.

References

Allegra, A., Sortino, G., Inglese, P., Settanni, L., Todaro, A., & Gallotta, A. (2017). The effectiveness of Opuntia ficus-indica mucilage edible coating on post-harvest maintenance of 'Dottato' fig (Ficus carica L.) fruit. *Food Packaging and Shelf Life*, *12*, 135–141. https://doi.org/10.1016/j.fpsl.2017.04.010

Alves, M. M., Gonçalves, M. P., & Rocha, C. M. R. (2017). Effect of ferulic acid on the performance of soy protein isolate-based edible coatings applied to fresh-cut apples. *LWT*, *80*, 409–415. https://doi.org/10.1016/j.lwt.2017.03.013

Aparicio-García, P. F., Ventura-Aguilar, R. I., del Río-García, J. C., Hernández-López, M., Guillén-Sánchez, D., Salazar-Piña, D. A., Ramos-García, M. de L., & Bautista-Baños, S. (2021). Edible Chitosan/Propolis Coatings and Their Effect on Ripening, Development of Aspergillus flavus, and Sensory Quality in Fig Fruit, during Controlled Storage. *Plants*, *10*(1), 112. https://doi.org/10.3390/plants10010112

Arquelau, P. B. de F., Silva, V. D. M., Garcia, M. A. V. T., Araújo, R. L. B. de, & Fante, C. A. (2019). Characterization of edible coatings based on ripe "Prata" banana peel flour. *Food Hydrocolloids*, *89*, 570–578. https://doi.org/10.1016/j.foodhyd.2018.11.029

Aydogdu, A., Radke, C. J., Bezci, S., & Kirtil, E. (2020). Characterization of curcumin incorporated guar gum/orange oil antimicrobial emulsion films. *International Journal of Biological Macromolecules*, *148*, 110–120. https://doi.org/10.1016/j.ijbiomac.2019.12.255

Azmin, S. N. H. M., Hayat, N. A. binti M., & Nor, M. S. M. (2020). Development and characterization of food packaging bioplastic film from cocoa pod husk cellulose incorporated with sugarcane bagasse fibre. *Journal of Bioresources and Bioproducts*, *5*(4), 248–255. https://doi.org/10.1016/j.jobab.2020.10.003

Balasubramaniam, V. M., Chinnan, M. S., Mallikarjunan, P., & Phillips, R. D. (1997). The Effect of Edible Film on Oil Uptake and Moisture Retention of a Deep-Fat Fried Poultry Product. *Journal of Food Process Engineering*, *20*(1), 17–29. https://doi.org/10.1111/j.1745-4530.1997.tb00408.x

Baptista, R. C., Horita, C. N., & Sant'Ana, A. S. (2020). Natural products with preservative properties for enhancing the microbiological safety and extending the shelf-life of seafood: A review. *Food Research International*, *127*, 108762. https://doi.org/10.1016/j.foodres.2019.108762

Behbahani, B. A., & Imani Fooladi, A. A. (2018). Shirazi balangu (Lallemantia royleana) seed mucilage: Chemical composition, molecular weight, biological activity and its evaluation as edible coating on beefs. *International Journal of Biological Macromolecules*, *114*, 882–889. https://doi.org/10.1016/j.ijbiomac.2018.03.177

Beikzadeh, S., Khezerlou, A., Jafari, S. M., Pilevar, Z., & Mortazavian, A. M. (2020). Seed mucilages as the functional ingredients for biodegradable films and edible coatings in the food industry. *Advances in Colloid and Interface Science*, *280*, 102164. https://doi.org/10.1016/j.cis.2020.102164

Braga, A., Guerreiro, C., & Belo, I. (2018). Generation of Flavors and Fragrances Through Biotransformation and De Novo Synthesis. *Food and Bioprocess Technology*, *11*(12), 2217–2228. https://doi.org/10.1007/s11947-018-2180-8

Brito, T. B., Carrajola, J. F., Gonçalves, E. C. B. A., Martelli-Tosi, M., & Ferreira, M. S. L. (2019). Fruit and vegetable residues flours with different granulometry range as raw material for pectin-enriched biodegradable film preparation. *Food Research International*, *121*, 412–421. https://doi.org/10.1016/j.foodres.2019.03.058

Brychcy-Rajska, E. (2017). Edible protective films and coatings in food industry. *Journal of Food Microbiology*, *0*(0). https://www.alliedacademies.org/abstract/

Bucio, A., Moreno-Tovar, R., Bucio, L., Espinosa-Dávila, J., & Anguebes-Franceschi, F. (2021). Characterization of Beeswax, Candelilla Wax and Paraffin Wax for Coating Cheeses. *Coatings*, *11*(3), 261. https://doi.org/10.3390/coatings11030261

Cao, X., Islam, M. N., Chitrakar, B., Duan, Z., Xu, W., & Zhong, S. (2020). Effect of combined chlorogenic acid and chitosan coating on antioxidant, antimicrobial, and sensory properties of snakehead fish in cold storage. *Food Science & Nutrition*, *8*(2), 973–981. https://doi.org/10.1002/fsn3.1378

Cardoso, G. P., Dutra, M. P., Fontes, P. R., Ramos, A. de L. S., Gomide, L. A. de M., & Ramos, E. M. (2016). Selection of a chitosan gelatin-based edible coating for color preservation of beef in retail display. *Meat Science*, *114*, 85–94. https://doi.org/10.1016/j.meatsci.2015.12.012

Carneiro-da-Cunha, M. G., Cerqueira, M. A., Souza, B. W. S., Souza, M. P., Teixeira, J. A., & Vicente, A. A. (2009). Physical properties of edible coatings and films made with a polysaccharide from Anacardium occidentale L. *Journal of Food Engineering*, *95*(3), 379–385. https://doi.org/10.1016/j.jfoodeng.2009.05.020

Carpiné, D., Dagostin, J. L. A., Bertan, L. C., & Mafra, M. R. (2015). Development and Characterization of Soy Protein Isolate Emulsion-Based Edible Films with Added Coconut Oil for Olive Oil Packaging: Barrier, Mechanical, and Thermal Properties. *Food and Bioprocess Technology*, *8*(8), 1811–1823. https://doi.org/10.1007/s11947-015-1538-4

Chen, Y., Xu, L., Wang, Y., Chen, Z., Zhang, M., & Chen, H. (2020). Characterization and functional properties of a pectin/tara gum based edible film with ellagitannins from the unripe fruits of Rubus chingii Hu. *Food Chemistry*, *325*, 126964. https://doi.org/10.1016/j.foodchem.2020.126964

Chien, P.-J., Sheu, F., & Yang, F.-H. (2007). Effects of edible chitosan coating on quality and shelf life of sliced mango fruit. *Journal of Food Engineering*, *78*(1), 225–229. https://doi.org/10.1016/j.jfoodeng.2005.09.022

Chiumarelli, M., & Hubinger, M. D. (2012). Stability, solubility, mechanical and barrier properties of cassava starch – Carnauba wax edible coatings to preserve fresh-cut apples. *Food Hydrocolloids*, *28*(1), 59–67. https://doi.org/10.1016/j.foodhyd.2011.12.006

Colzato, M., Scramin, J. A., Forato, L. A., Colnago, L. A., & Assis, O. B. G. (2011). 1h Nmr Investigation of Oil Oxidation in Macadamia Nuts Coated with Zein-Based Films. *Journal of Food Processing and Preservation*, *35*(6), 790–796. https://doi.org/10.1111/j.1745-4549.2011.00530.x

Correa-Betanzo, J., Jacob, J. K., Perez-Perez, C., & Paliyath, G. (2011). Effect of a sodium caseinate edible coating on berry cactus fruit (Myrtillocactus geometrizans) phytochemicals. *Food Research International*, *44*(7), 1897–1904. https://doi.org/10.1016/j.foodres.2010.10.053

Das, P., Borah, P. P., & Badwaik, L. S. (2018). Transformation of Chicken Feather Keratin and Pomelo Peel Pectin into Biodegradable Composite Film. *Journal of Polymers and the Environment*, *26*(5), 2120–2129. https://doi.org/10.1007/s10924-017-1109-z

Davachi, S. M., Pottackal, N., Torabi, H., & Abbaspourrad, A. (2021). Development and characterization of probiotic mucilage based edible films for the preservation of fruits and vegetables. *Scientific Reports*, *11*(1), 16608. https://doi.org/10.1038/s41598-021-95994-5

Davoodi, S., Davachi, S. M., Ghorbani Golkhajeh, A., Shekarabi, A. S., & Abbaspourrad, A. (2020). Development and Characterization of Salvia macrosiphon/Chitosan Edible Films. *ACS Sustainable Chemistry & Engineering*, *8*(3), 1487–1496. https://doi.org/10.1021/acssuschemeng.9b05894

Dhaka, R. K., & Upadhyay, A. (2018). Edible films and coatings: A brief overview. *The Pharma Innovation Journal*, *7*(7), 331–333.

Dosoky, N. S., & Setzer, W. N. (2018). Biological Activities and Safety of Citrus spp. Essential Oils. *International Journal of Molecular Sciences*, *19*(7), 1966. https://doi.org/10.3390/ijms19071966

El Assimi, T., Lakbita, O., El Meziane, A., Khouloud, M., Dahchour, A., Beniazza, R., Boulif, R., Raihane, M., & Lahcini, M. (2020). Sustainable coating material based on chitosan-clay composite and paraffin wax for slow-release DAP fertilizer. *International Journal of Biological Macromolecules*, *161*, 492–502. https://doi.org/10.1016/j.ijbiomac.2020.06.074

El-Sayed, H. S., El-Sayed, S. M., Mabrouk, A. M. M., Nawwar, G. A., & Youssef, A. M. (2021). Development of Eco-friendly Probiotic Edible Coatings Based on Chitosan, Alginate and Carboxymethyl Cellulose for Improving the Shelf Life of UF Soft Cheese. *Journal of Polymers and the Environment*, *29*(6), 1941–1953. https://doi.org/10.1007/s10924-020-02003-3

Emam-Djomeh, Z., Moghaddam, A., & Ardakani, S. A. Y. (2015). Antimicrobial Activity of Pomegranate (Punica granatum L.) Peel Extract, Physical, Mechanical, Barrier and Antimicrobial Properties of Pomegranate Peel Extract-incorporated Sodium Caseinate Film and Application in Packaging for Ground Beef. *Packaging Technology and Science*, *28*(10), 869–881. https://doi.org/10.1002/pts.2145

Fagundes, C., Palou, L., Monteiro, A. R., & Pérez-Gago, M. B. (2015). Hydroxypropyl methylcellulose-beeswax edible coatings formulated with antifungal food additives to reduce alternaria black spot and maintain postharvest quality of cold-stored cherry tomatoes. *Scientia Horticulturae*, *193*, 249–257. https://doi.org/10.1016/j.scienta.2015.07.027

Farooq, M., Azadfar, E., Rusu, A., Trif, M., Poushi, M. K., & Wang, Y. (2021). Improving the Shelf Life of Peeled Fresh Almond Kernels by Edible Coating with Mastic Gum. *Coatings*, *11*(6), 618. https://doi.org/10.3390/coatings11060618

Fernández-Pan, I., Carrión-Granda, X., & Maté, J. I. (2014). Antimicrobial efficiency of edible coatings on the preservation of chicken breast fillets. *Food Control*, *36*(1), 69–75. https://doi.org/10.1016/j.foodcont.2013.07.032

Food Loss and Food Waste | FAO | Food and Agriculture Organization of the United Nations. (n.d.). Retrieved June 17, 2021, from http://www.fao.org/food-loss-and-food-waste/flw-data)

Frazão, G. G. S., Blank, A. F., & de Aquino Santana, L. C. L. (2017). Optimisation of edible chitosan coatings formulations incorporating Myrcia ovata Cambessedes essential oil with antimicrobial potential against foodborne bacteria and natural microflora of mangaba fruits. *LWT - Food Science and Technology*, *79*, 1–10. https://doi.org/10.1016/j.lwt.2017.01.011

Galus, S., Arik Kibar, E. A., Gniewosz, M., & Kraśniewska, K. (2020). Novel Materials in the Preparation of Edible Films and Coatings—A Review. *Coatings*, *10*(7), 674. https://doi.org/10.3390/coatings10070674

Galus, S., & Kadzińska, J. (2015). Food applications of emulsion-based edible films and coatings. *Trends in Food Science & Technology*, *45*(2), 273–283. https://doi.org/10.1016/j.tifs.2015.07.011

Ganiari, S., Choulitoudi, E., & Oreopoulou, V. (2017). Edible and active films and coatings as carriers of natural antioxidants for lipid food. *Trends in Food Science &*

Technology, *68*, 70–82. https://doi.org/10.1016/j.tifs.2017.08.009

García, M. A., Ferrero, C., Bértola, N., Martino, M., & Zaritzky, N. (2002). Edible coatings from cellulose derivatives to reduce oil uptake in fried products. *Innovative Food Science & Emerging Technologies*, *3*(4), 391–397. https://doi.org/10.1016/S1466-8564(02)00050-4

Genevois, C. E., de Escalada Pla, M. F., & Flores, S. K. (2016). Application of edible coatings to improve global quality of fortified pumpkin. *Innovative Food Science & Emerging Technologies*, *33*, 506–514. https://doi.org/10.1016/j.ifset.2015.11.001

Ghaouth, A. E., Arul, J., Ponnampalam, R., & Boulet, M. (1991). USE of CHITOSAN COATING to REDUCE WATER LOSS and MAINTAIN QUALITY of CUCUMBER and BELL PEPPER FRUITS. *Journal of Food Processing and Preservation*, *15*(5), 359–368. https://doi.org/10.1111/j.1745-4549.1991.tb00178.x

Ghosh, T., Mondal, K., Giri, B. S., & Katiyar, V. (2021). Silk nanodisc based edible chitosan nanocomposite coating for fresh produces: A candidate with superior thermal, hydrophobic, optical, mechanical and food properties. *Food Chemistry*, *360*, 130048. https://doi.org/10.1016/j.foodchem.2021.130048

Guerreiro, A. C. (2016). *Innovative edible coatings to improve storage of small fruits and fresh-cut*. https://sapientia.ualg.pt/handle/10400.1/8988

Guerreiro, A. C., Gago, C. M. L., Faleiro, M. L., Miguel, M. G. C., & Antunes, M. D. C. (2017). The effect of edible coatings on the nutritional quality of 'Bravo de Esmolfe' fresh-cut apple through shelf-life. *LWT*, *75*, 210–219. https://doi.org/10.1016/j.lwt.2016.08.052

Gutiérrez, T. J., Herniou-Julien, C., Álvarez, K., & Alvarez, V. A. (2018). Structural properties and in vitro digestibility of edible and pH-sensitive films made from guinea arrowroot starch and wastes from wine manufacture. *Carbohydrate Polymers*, *184*, 135–143. https://doi.org/10.1016/j.carbpol.2017.12.039

Han, C., Zhao, Y., Leonard, S. W., & Traber, M. G. (2004). Edible coatings to improve storability and enhance nutritional value of fresh and frozen strawberries (Fragaria × ananassa) and raspberries (Rubus ideaus). *Postharvest Biology and Technology*, *33*(1), 67–78. https://doi.org/10.1016/j.postharvbio.2004.01.008

Hashemi Gahruie, H., Mostaghimi, M., Ghiasi, F., Tavakoli, S., Naseri, M., & Hosseini, S. M. H. (2020). The effects of fatty acids chain length on the techno-functional properties of basil seed gum-based edible films. *International Journal of Biological Macromolecules*, *160*, 245–251. https://doi.org/10.1016/j.ijbiomac.2020.05.136

Hassan, B., Chatha, S. A. S., Hussain, A. I., Zia, K. M., & Akhtar, N. (2018). Recent advances on polysaccharides, lipids and protein based edible films and coatings: A review. *International Journal of Biological Macromolecules*, *109*, 1095–1107. https://doi.org/10.1016/j.ijbiomac.2017.11.097

Hofmanová, J. K., Rajabi-Siahboomi, A., Haque, S., Mason, J., Teckoe, J., To, D., & Batchelor, H. K. (2019). Developing methodology to evaluate the oral sensory features of pharmaceutical tablet coatings. *International Journal of Pharmaceutics*, *562*, 212–217. https://doi.org/10.1016/j.ijpharm.2019.03.046

Homayouni, H., Kavoosi, G., & Nassiri, S. M. (2017). Physicochemical, antioxidant and antibacterial properties of dispersion made from tapioca and gelatinized tapioca starch incorporated with carvacrol. *LWT*, *77*, 503–509. https://doi.org/10.1016/j.lwt.2016.12.007

Homsaard, N., Kodsangma, A., Jantrawut, P., Rachtanapun, P., Leksawasdi, N., Phimolsiripol, Y., Seesuriyachan, P., Chaiyaso, T., Sommano, S. R., Rohindra, D., & Jantanasakulwong, K. (n.d.). Efficacy of cassava starch blending with gelling agents and palm oil coating in improving egg shelf life. *International Journal of Food Science & Technology*, *n/a*(n/a). https://doi.org/10.1111/ijfs.14675

Hosseini, S. F., Rezaei, M., Zandi, M., & Ghavi, F. F. (2013). Preparation and functional properties of fish gelatin–chitosan blend edible films. *Food Chemistry*, *136*(3), 1490–1495. https://doi.org/10.1016/j.foodchem.2012.09.081

Huang, T., Qian, Y., Wei, J., & Zhou, C. (2019). Polymeric Antimicrobial Food Packaging and Its Applications. *Polymers*, *11*(3), 560. https://doi.org/10.3390/polym11030560

Huang, X., Luo, X., Liu, L., Dong, K., Yang, R., Lin, C., Song, H., Li, S., & Huang, Q. (2020). Formation mechanism of egg white protein/κ-Carrageenan composite film and its application to oil packaging. *Food Hydrocolloids*, *105*, 105780. https://doi.org/10.1016/j.foodhyd.2020.105780

Hussain, Md. A., Sumon, T. A., Mazumder, S. K., Ali, M. M., Jang, W. J., Abualreesh, M. H., Sharifuzzaman, S. M., Brown, C. L., Lee, H.-T., Lee, E.-W., & Hasan, Md. T. (2021). Essential oils and chitosan as alternatives to chemical preservatives for fish and fisheries products: A review. *Food Control*, 108244. https://doi.org/10.1016/j.foodcont.2021.108244

Kang, H. J., Jo, C., Kwon, J. H., Kim, J. H., Chung, H. J., & Byun, M. W. (2007). Effect of a pectin-based edible coating containing green tea powder on the quality of irradiated pork patty. *Food Control*, *18*(5), 430–435. https://doi.org/10.1016/j.foodcont.2005.11.010

Kilincceker, O., Dogan, İ. S., & Kucukoner, E. (2009). Effect of edible coatings on the quality of frozen fish fillets. *LWT - Food Science and Technology*, *42*(4), 868–873. https://doi.org/10.1016/j.lwt.2008.11.003

Kim, H., Beak, S.-E., Yang, S.-Y., & Song, K. B. (2018). Application of an antimicrobial packaging material from chicken bone gelatine and cinnamon bark oil to mozzarella cheese. *International Journal of Food Science & Technology*, *53*(3), 619–625. https://doi.org/10.1111/ijfs.13636

Kocira, A., Kozłowicz, K., Panasiewicz, K., Staniak, M., Szpunar-Krok, E., & Hortyńska, P. (2021). Polysaccharides as Edible Films and Coatings: Characteristics and Influence on Fruit and Vegetable Quality—A Review. *Agronomy*, *11*(5), 813. https://doi.org/10.3390/agronomy11050813

Kontogiorgos, V. (2019). Galactomannans (Guar, Locust Bean, Fenugreek, Tara). In L. Melton, F. Shahidi, & P. Varelis (Eds.), *Encyclopedia of Food Chemistry* (pp. 109–113). Academic Press. https://doi.org/10.1016/B978-0-08-100596-5.21589-8

Kouhi, M., Prabhakaran, M. P., & Ramakrishna, S. (2020). Edible polymers: An insight into its application in food, biomedicine and cosmetics. *Trends in Food Science & Technology*, *103*, 248–263. https://doi.org/10.1016/j.tifs.2020.05.025

Kowalczyk, D., & Pikula, E. (2010). Effect of edible protein-wax coating on storage quality of table grapes (Vitis vinifera L.). *Zywnosc Nauka Technologia Jakosc (Poland)*. https://agris.fao.org/agris-search/search.do?recordID=PL2011000607

Kowalczyk, D., Pikula, E., & Baraniak, B. (2010). Effect of edible protein-wax coating on quality of cold-stored broccoli. *Zywnosc.Nauka.Technologia.Jakosc/Food.Science.Technology.Quality*, *17*. https://doi.org/10.15193/zntj/2010/73/120-133

La, D. D., Nguyen-Tri, P., Le, Khoa. H., Nguyen, P. T. M., Nguyen, M. D.-B., Vo, A. T. K., Nguyen, M. T. H., Chang, S. W., Tran, L. D., Chung, W. J., & Nguyen, D. D. (2021). Effects of antibacterial ZnO nanoparticles on the performance of a chitosan/gum arabic edible coating for post-harvest banana preservation. *Progress in Organic Coatings*, *151*, 106057. https://doi.org/10.1016/j.porgcoat.2020.106057

Lacroix, M., Ouattara, B., Saucier, L., Giroux, M., & Smoragiewicz, W. (2004). Effect of gamma irradiation in presence of ascorbic acid on microbial composition and TBARS concentration of ground beef coated with an edible active coating. *Radiation Physics and Chemistry*, *71*(1), 73–77. https://doi.org/10.1016/j.radphyschem.2004.04.057

Lacroix, M., & Vu, K. D. (2014). Chapter 11 - Edible Coating and Film Materials: Proteins. In J. H. Han (Ed.), *Innovations in Food Packaging (Second Edition)* (pp. 277–304). Academic Press. https://doi.org/10.1016/B978-0-12-394601-0.00011-4

Lee, J. Y., Park, H. J., Lee, C. Y., & Choi, W. Y. (2003). Extending shelf-life of minimally processed apples with edible coatings and antibrowning agents. *LWT - Food Science and Technology*, *36*(3), 323–329. https://doi.org/10.1016/S0023-

6438(03)00014-8

Lima, Á. M., Cerqueira, M. A., Souza, B. W. S., Santos, E. C. M., Teixeira, J. A., Moreira, R. A., & Vicente, A. A. (2010). New edible coatings composed of galactomannans and collagen blends to improve the postharvest quality of fruits – Influence on fruits gas transfer rate. *Journal of Food Engineering*, *97*(1), 101–109. https://doi.org/10.1016/j.jfoodeng.2009.09.021

Lin, D., & Zhao, Y. (2007). Innovations in the Development and Application of Edible Coatings for Fresh and Minimally Processed Fruits and Vegetables. *Comprehensive Reviews in Food Science and Food Safety*, *6*(3), 60–75. https://doi.org/10.1111/j.1541-4337.2007.00018.x

Liu, C., Jin, T., Liu, W., Hao, W., Yan, L., & Zheng, L. (2021). Effects of hydroxyethyl cellulose and sodium alginate edible coating containing asparagus waste extract on postharvest quality of strawberry fruit. *LWT*, *148*, 111770. https://doi.org/10.1016/j.lwt.2021.111770

Marchiore, N. G., Manso, I. J., Kaufmann, K. C., Lemes, G. F., Pizolli, A. P. de O., Droval, A. A., Bracht, L., Gonçalves, O. H., & Leimann, F. V. (2017). Migration evaluation of silver nanoparticles from antimicrobial edible coating to sausages. *LWT - Food Science and Technology*, *76*, 203–208. https://doi.org/10.1016/j.lwt.2016.06.013

Martínez-González, M. del C., Bautista-Baños, S., Correa-Pacheco, Z. N., Corona-Rangel, M. L., Ventura-Aguilar, R. I., Del Río-García, J. C., & Ramos-García, M. de L. (2020). Effect of Nanostructured Chitosan/Propolis Coatings on the Quality and Antioxidant Capacity of Strawberries During Storage. *Coatings*, *10*(2), 90. https://doi.org/10.3390/coatings10020090

Martiñon, M. E., Moreira, R. G., Castell-Perez, M. E., & Gomes, C. (2014). Development of a multilayered antimicrobial edible coating for shelf-life extension of fresh-cut cantaloupe (Cucumis melo L.) stored at 4   C. *LWT - Food Science and Technology*, *56*(2), 341–350. https://doi.org/10.1016/j.lwt.2013.11.043

McHugh, T. H., & Senesi, E. (2000). Apple Wraps: A Novel Method to Improve the Quality and Extend the Shelf Life of Fresh-cut Apples. *Journal of Food Science*, *65*(3), 480–485. https://doi.org/10.1111/j.1365-2621.2000.tb16032.x

Mehyar, G. F., Al-Ismail, K., Han, J. H., & Chee, G. W. (2012). Characterization of Edible Coatings Consisting of Pea Starch, Whey Protein Isolate, and Carnauba Wax and their Effects on Oil Rancidity and Sensory Properties of Walnuts and Pine Nuts. *Journal of Food Science*, *77*(2), E52–E59. https://doi.org/10.1111/j.1750-3841.2011.02559.x

Mei, Y., & Zhao, Y. (2003). Barrier and Mechanical Properties of Milk Protein-Based Edible Films Containing Nutraceuticals. *Journal of Agricultural and Food Chemistry*, *51*(7), 1914–1918. https://doi.org/10.1021/jf025944h

Molefi, J. A., Luyt, A. S., & Krupa, I. (2010). Comparison of LDPE, LLDPE and HDPE as matrices for phase change materials based on a soft Fischer–Tropsch paraffin wax. *Thermochimica Acta*, *500*(1), 88–92. https://doi.org/10.1016/j.tca.2010.01.002

Monteiro Fritz, A. R., de Matos Fonseca, J., Trevisol, T. C., Fagundes, C., & Valencia, G. A. (2019). Active, Eco-Friendly and Edible Coatings in the Post-Harvest A Critical Discussion. In T. J. Gutiérrez (Ed.), *Polymers for Agri-Food Applications* (pp. 433–463). Springer International Publishing. https://doi.org/10.1007/978-3-030-19416-1_22

Moreno, M. A., Vallejo, A. M., Ballester, A.-R., Zampini, C., Isla, M. I., López-Rubio, A., & Fabra, M. J. (2020). Antifungal edible coatings containing Argentinian propolis extract and their application in raspberries. *Food Hydrocolloids*, *107*, 105973. https://doi.org/10.1016/j.foodhyd.2020.105973

Muhammad, Z., Ramzan, R., Zhang, R., & Zhang, M. (2021). Resistant Starch-Based Edible Coating Composites for Spray-Dried Microencapsulation of Lactobacillus acidophilus, Comparative Assessment of Thermal Protection, In Vitro Digestion and Physicochemical Characteristics. *Coatings*, *11*(5), 587. https://doi.org/10.3390/coatings11050587

Nasrin, T. A. A., Rahman, M. A., Arfin, M. S., Islam, M. N., & Ullah, M. A. (2020). Effect of novel coconut oil and beeswax edible coating on postharvest quality of lemon at ambient storage. *Journal of Agriculture and Food Research*, *2*, 100019. https://doi.org/10.1016/j.jafr.2019.100019

Nelson, K. L., & Fennema, O. R. (1991). Methylcellulose Films to Prevent Lipid Migration in Confectionery Products. *Journal of Food Science*, *56*(2), 504–509. https://doi.org/10.1111/j.1365-2621.1991.tb05314.x

Ntrallou, K., Gika, H., & Tsochatzis, E. (2020). Analytical and Sample Preparation Techniques for the Determination of Food Colorants in Food Matrices. *Foods*, *9*(1), 58. https://doi.org/10.3390/foods9010058

Ochoa, E., Sa&uacute, Saucedo-Pompa, L., Rojas-Molina, R., Garza, H. de la, Charles-Rodr&iacute, A. V., guez, Crist&oacute, No&eacute, B., & Aguilar. (2011). Evaluation of a Candelilla Wax-Based Edible Coating to Prolong the Shelf-Life Quality and Safety of Apples. *American Journal of Agricultural and Biological Sciences*, *6*(1), 92–98. https://doi.org/10.3844/ajabssp.2011.92.98

Ochoa-Yepes, O., Medina-Jaramillo, C., Guz, L., & Famá, L. (2018). Biodegradable and Edible Starch Composites with Fiber-Rich Lentil Flour to Use as Food Packaging. *Starch - Stärke*, *70*(7–8), 1700222. https://doi.org/10.1002/star.201700222

Oluba, O. M., Osayame, E., & Shoyombo, A. O. (2021). Production and characterization of keratin-starch bio-composite film from chicken feather waste and turmeric starch. *Biocatalysis and Agricultural Biotechnology*, *33*, 101996. https://doi.org/10.1016/j.bcab.2021.101996

Oms-Oliu, G., Soliva-Fortuny, R., & Martín-Belloso, O. (2008). Using polysaccharide-based edible coatings to enhance quality and antioxidant properties of fresh-cut melon. *LWT - Food Science and Technology*, *41*(10), 1862–1870. https://doi.org/10.1016/j.lwt.2008.01.007

Padua, G. W., & Wang, Q. (2002). Formation and properties of corn zein films and coatings. *Protein-Based Films and Coatings*, 43–67.

Park, S., & Zhao, Y. (2004). Incorporation of a High Concentration of Mineral or Vitamin into Chitosan-Based Films. *Journal of Agricultural and Food Chemistry*, *52*(7), 1933–1939. https://doi.org/10.1021/jf034612p

Pavlath, A. E., & Orts, W. (2009). Edible Films and Coatings: Why, What, and How? In K. C. Huber & M. E. Embuscado (Eds.), *Edible Films and Coatings for Food Applications* (pp. 1–23). Springer. https://doi.org/10.1007/978-0-387-92824-1_1

Pérez-Gago, M. B., & Rhim, J.-W. (2014). Chapter 13 - Edible Coating and Film Materials: Lipid Bilayers and Lipid Emulsions. In J. H. Han (Ed.), *Innovations in Food Packaging (Second Edition)* (pp. 325–350). Academic Press. https://doi.org/10.1016/B978-0-12-394601-0.00013-8

Perinelli, D. R., Palmieri, G. F., Cespi, M., & Bonacucina, G. (2020). Encapsulation of Flavours and Fragrances into Polymeric Capsules and Cyclodextrins Inclusion Complexes: An Update. *Molecules*, *25*(24), 5878. https://doi.org/10.3390/molecules25245878

Pop, O. L., Pop, C. R., Dufrechou, M., Vodnar, D. C., Socaci, S. A., Dulf, F. V., Minervini, F., & Suharoschi, R. (2020). Edible Films and Coatings Functionalization by Probiotic Incorporation: A Review. *Polymers*, *12*(1), 12. https://doi.org/10.3390/polym12010012

Poverenov, E., Zaitsev, Y., Arnon, H., Granit, R., Alkalai-Tuvia, S., Perzelan, Y., Weinberg, T., & Fallik, E. (2014). Effects of a composite chitosan–gelatin edible coating on postharvest quality and storability of red bell peppers. *Postharvest Biology and Technology*, *96*, 106–109. https://doi.org/10.1016/j.postharvbio.2014.05.015

Proaño, J. L., Salgado, P. R., Cian, R. E., Mauri, A. N., & Drago, S. R. (2020). Physical, structural and antioxidant properties of brewer's spent grain protein films. *Journal of the Science of Food and Agriculture*, *100*(15), 5458–5465. https://doi.org/10.1002/jsfa.10597

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Spectroscopy and Imaging | SpringerLink. (n.d.). Retrieved June 8, 2021, from https://link.springer.com/chapter/10.1007/1-4020-3910-7_215

Rangel-Marrón, M., Mani-López, E., Palou, E., & López-Malo, A. (2019). Effects of alginate-glycerol-citric acid concentrations on selected physical, mechanical, and barrier properties of papaya puree-based edible films and coatings, as evaluated by response surface methodology. *LWT*, *101*, 83–91. https://doi.org/10.1016/j.lwt.2018.11.005

Robledo, N., López, L., Bunger, A., Tapia, C., & Abugoch, L. (2018). Effects of Antimicrobial Edible Coating of Thymol Nanoemulsion/Quinoa Protein/Chitosan on the Safety, Sensorial Properties, and Quality of Refrigerated Strawberries (Fragaria × ananassa) Under Commercial Storage Environment. *Food and Bioprocess Technology*, *11*(8), 1566–1574. https://doi.org/10.1007/s11947-018-2124-3

Robles-Flores, G. del C., Abud-Archila, M., Ventura-Canseco, L. M. C., Meza-Gordillo, R., Grajales-Lagunes, A., Ruiz-Cabrera, M. A., & Gutiérrez-Miceli, F. A. (2018). Development and Evaluation of a Film and Edible Coating Obtained from the Cajanus cajan Seed Applied to Fresh Strawberry Fruit. *Food and Bioprocess Technology*, *11*(12), 2172–2181. https://doi.org/10.1007/s11947-018-2175-5

Rodriguez-Turienzo, L., Cobos, A., & Diaz, O. (2012). Effects of edible coatings based on ultrasound-treated whey proteins in quality attributes of frozen Atlantic salmon (Salmo salar). *Innovative Food Science & Emerging Technologies*, *14*, 92–98. https://doi.org/10.1016/j.ifset.2011.12.003

Rojas-Graü, M. A., Raybaudi-Massilia, R. M., Soliva-Fortuny, R. C., Avena-Bustillos, R. J., McHugh, T. H., & Martín-Belloso, O. (2007). Apple puree-alginate edible coating as carrier of antimicrobial agents to prolong shelf-life of fresh-cut apples. *Postharvest Biology and Technology*, *45*(2), 254–264. https://doi.org/10.1016/j.postharvbio.2007.01.017

Rosyada, A., Sunarharum, W. B., & Waziiroh, E. (2019). Characterization of chitosan nanoparticles as an edible coating material. *IOP Conference Series: Earth and Environmental Science*, *230*, 012043. https://doi.org/10.1088/1755-1315/230/1/012043

Sabaghi, M., Maghsoudlou, Y., Khomeiri, M., & Ziaiifar, A. M. (2015). Active edible coating from chitosan incorporating green tea extract as an antioxidant and antifungal on fresh walnut kernel. *Postharvest Biology and Technology*, *110*, 224–228. https://doi.org/10.1016/j.postharvbio.2015.08.025

Sharma, S., & Rao, T. V. R. (2015). Xanthan gum based edible coating enriched with cinnamic acid prevents browning and extends the shelf-life of fresh-cut pears. *LWT - Food Science and Technology*, *62*(1, Part 2), 791–800. https://doi.org/10.1016/j.lwt.2014.11.050

Sigurdson, G. T., Tang, P., & Giusti, M. M. (2017). Natural Colorants: Food Colorants from Natural Sources. *Annual Review of Food Science and Technology*, *8*(1), 261–280. https://doi.org/10.1146/annurev-food-030216-025923

Sondari, D. (2019). Modification of Sago Starch for Edible Coating. *IOP Conference Series: Materials Science and Engineering*, *543*, 012013. https://doi.org/10.1088/1757-899X/543/1/012013

Sothornvit, R., & Pitak, N. (2007). Oxygen permeability and mechanical properties of banana films. *Food Research International*, *40*(3), 365–370. https://doi.org/10.1016/j.foodres.2006.10.010

Subroto, E., & Nurannisa, R. (2021). The Recent Application Of Palm Stearin In Food Industry: A Review. *International Journal of Scientific & Technology Research*, *9*, 2593–2597.

Sukyai, P., Anongjanya, P., Bunyahwuthakul, N., Kongsin, K., Harnkarnsujarit, N., Sukatta, U., Sothornvit, R., & Chollakup, R. (2018). Effect of cellulose nanocrystals from sugarcane bagasse on whey protein isolate-based films. *Food Research International*, *107*, 528–535. https://doi.org/10.1016/j.foodres.2018.02.052

Talens, P., Pérez-Masía, R., Fabra, M. J., Vargas, M., & Chiralt, A. (2012). Application of edible coatings to partially dehydrated pineapple for use in fruit–cereal products. *Journal of Food Engineering*, *112*(1), 86–93. https://doi.org/10.1016/j.jfoodeng.2012.03.022

Tassoni, A., Tedeschi, T., Zurlini, C., Cigognini, I. M., Petrusan, J.-I., Rodríguez, Ó., Neri, S., Celli, A., Sisti, L., Cinelli, P., Signori, F., Tsatsos, G., Bondi, M., Verstringe, S., Bruggerman, G., & Corvini, P. F. X. (2020). State-of-the-Art Production Chains for Peas, Beans and Chickpeas—Valorization of Agro-Industrial Residues and Applications of Derived Extracts. *Molecules*, *25*(6), 1383. https://doi.org/10.3390/molecules25061383

Terpou, A., Nigam, P. S., Bosnea, L., & Kanellaki, M. (2018). Evaluation of Chios mastic gum as antimicrobial agent and matrix forming material targeting probiotic cell encapsulation for functional fermented milk production. *LWT*, *97*, 109–116. https://doi.org/10.1016/j.lwt.2018.06.045

Tomás, S. A., Bosquez-Molina, E., Stolik, S., & Sánchez, F. (2005). Effects of mesquite gum-candelilla wax based edible coatings on the quality of guava fruit (Psidium guajava L.). *Journal de Physique IV*, *125*, 889–892. https://doi.org/10.1051/jp4:2005125206

Tyburcy, A., & Kozyra, D. (2010). Effects of composite surface coating and pre-drying on the properties of kabanosy dry sausage. *Meat Science*, *86*(2), 405–410. https://doi.org/10.1016/j.meatsci.2010.05.025

Viña, S. Z., Mugridge, A., García, M. A., Ferreyra, R. M., Martino, M. N., Chaves, A. R., & Zaritzky, N. E. (2007). Effects of polyvinylchloride films and edible starch coatings on quality aspects of refrigerated Brussels sprouts. *Food Chemistry*, *103*(3), 701–709. https://doi.org/10.1016/j.foodchem.2006.09.010

Wang, X., Kong, D., Ma, Z., & Zhao, R. (2015). Effect of carrot puree edible films on quality preservation of fresh-cut carrots. *Irish Journal of Agricultural and Food Research*, *54*(1), 64–71.

Williams, N. T. (2010). Probiotics. *American Journal of Health-System Pharmacy*, *67*(6), 449–458. https://doi.org/10.2146/ajhp090168

Wrolstad, R. E., & Culver, C. A. (2012). Alternatives to Those Artificial FD&C Food Colorants. *Annual Review of Food Science and Technology*, *3*(1), 59–77. https://doi.org/10.1146/annurev-food-022811-101118

Wu, H., Lei, Y., Zhu, R., Zhao, M., Lu, J., Xiao, D., Jiao, C., Zhang, Z., Shen, G., & Li, S. (2019). Preparation and characterization of bioactive edible packaging films based on pomelo peel flours incorporating tea polyphenol. *Food Hydrocolloids*, *90*, 41–49. https://doi.org/10.1016/j.foodhyd.2018.12.016

Wu, S., & Chen, J. (2013). Using pullulan-based edible coatings to extend shelf-life of fresh-cut 'Fuji' apples. *International Journal of Biological Macromolecules*, *55*, 254–257. https://doi.org/10.1016/j.ijbiomac.2013.01.012

Xiao, Q. (2021). Coating and Film-Forming Properties. In Y. Fang, H. Zhang, & K. Nishinari (Eds.), *Food Hydrocolloids: Functionalities and Applications* (pp. 267–306). Springer. https://doi.org/10.1007/978-981-16-0320-4_8

YB, B. & Manjula. (2019). Influence of composite edible coating systems on preservation of fresh meat cuts and products: A brief review on their trends and applications. *International Food Research Journal*, *26*, 377–392.

Yong, H., & Liu, J. (2021). Active packaging films and edible coatings based on polyphenol-rich propolis extract: A review. *Comprehensive Reviews in Food Science and Food Safety*, *20*(2), 2106–2145. https://doi.org/10.1111/1541-4337.12697

Zhang, B., Liu, Y., Wang, H., Liu, W., Cheong, K., & Teng, B. (2021). Effect of sodium alginate-agar coating containing ginger essential oil on the shelf life and quality of beef. *Food Control*, 108216. https://doi.org/10.1016/j.foodcont.2021.108216

Zhang, L., Chen, F., Lai, S., Wang, H., & Yang, H. (2018). Impact of soybean protein isolate-chitosan edible coating on the softening of apricot fruit during storage. *LWT*, *96*, 604–611. https://doi.org/10.1016/j.lwt.2018.06.011

Zhao, Y., & McDaniel, M. (2005). 24—Sensory quality of foods associated with edible film and coating systems and shelf-life extension. In J. H. Han (Ed.), *Innovations in Food Packaging* (pp. 434–453). Academic Press. https://doi.org/10.1016/B978-012311632-1/50056-5