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Edible biofilms and coatings; its characterization and advanced industrial applications

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ABSTRACT: Edible films and coatings are layers of edible biopolymers (proteins, lipids and polysaccharides) that can be used as an alternate for plastic packaging materials, because plastic packaging is causing environmental pollution and it can deteriorate human health when come in contact with the food product. Along with their environment friendly nature they can carry anti-oxidants, anti-microbials, anti-browning agents, neutraceuticals, pharmaceuticals, colorants, flavors and desired additives to the food product which can prolong their shelf life and increase the aesthetic properties of the food product. Edible films are generated separately by solvent casting and extrusion while edible coating is applied on the food product by spraying or dipping. The conjugation of these edible biopolymers with the nanotechnology (nanoencapsulation, nanofibers and nanoliposomes) can initiate a controlled and targeted release of the additives added in the film or coating. In this review article several novel biopolymers for edible films and coatings have been discussed along with their applications in fruits and vegetable, meat and poultry and dairy industry.

1. INTRODUCTION

The non-renewability and non-biodegradability of plastic makes it a hazard for environment as it produces a massive amount of solid waste and contributes largely to environmental pollution. As of 2016, from a total of 2.01 billion metric tons of solid waste produced, about 12% of it was the products of petrochemical origin (Ribeiro et al., 2021). As far as food industry is concerned, the packaging of food products is done with the plastic package which is directly involved in environmental pollution. The foundation of plastic being so much responsible for much of the solid waste produced is its cheap production methods, convenience of transport and light weight (Porta et al., 2011; Ribeiro et al., 2021). Recent experiments show that the interaction of food with the packaging of petrochemical origin have drastic effects on human health due to the presence of cancer causing heavy metals like cadmium and mercury. Furthermore, the burning of this plastic solid waste can release sulfur oxides, nitrogen oxides and carbon oxides that is a threat for air pollution (Hammam, 2019).

As the world is progressing, and people are getting aware of the environmental pollution, the demand for health conscious and environmental friendly goods is increasing. One such example of this is the edible films and coatings. Edible coating or film is a type of food packaging material that is generated from renewable sources like polysaccharide, protein or lipid and can be ingested with the food itself. With a thickness of less than 0.3 mm, edible coatings increase the shelf life of food and are biodegradable (Kandasamy et al., 2021; Ribeiro et al., 2021). With various other advantages, the edible films and coatings can be used to incorporate a variety of additives in food materials, like probiotics, antimicrobials and anti-oxidants (Chaudhary et al., 2020). These films and coatings allow the exchange of gases between environment and the food material due to their semi permeable nature. To aid the marketing area of fruits and vegetables, researchers are making edible films with sensory attractiveness by adding certain flavors, dyes and sweeteners to elevate their aesthetic beauty (Kocira et al., 2021).

While the similarity in function is quite evident, the implementation design of edible films and coatings on food product is different. The edible film is generated away from the food product and after its generation it is wrapped around or in between the food layers. The edible coating is applied directly to the food product by immersing the product in it or spraying the coating on the food itself (Ribeiro et al., 2021). Edible films and coatings are also differ in their thickness with films usually are thicker than the coatings due to their solid film like nature (Kandasamy et al., 2021).

Edible films and coatings dates back in the 13^{th} century when first edible film was produced with the soy milk skin called yuba but its purpose was never to substitute or entirely

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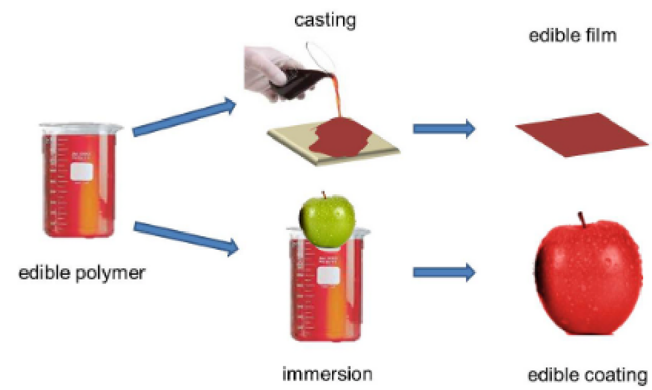

Figure 1. Edible film vs edible coating preparation (Kouhi et al., n.d.)

revising the traditional packaging materials. In the last century, as the environmental concerns arise, the pace of re-introducing the age old technique also elevated. The accepted ones among them are polysaccharide, protein and lipid based edible coatings and films. Films and coatings with antimicrobial agents in them are the concern of many scientists. Commonly, essential oils, enzymes, organic acids and silver ions are used as antimicrobial agents. For fungi like candida albicans and gram negative bacteria peppermint oil appears to be effective (Kandirmaz & Zelzele, 2020). Among polysaccharides cellulose based, chitin and chitosan based and starch based films are widespread (Hassan et al., 2018). Chitosan based edible films are non toxic, non allergenic, anti fungal, anti-bacterial and biodegradable (Chaudhary et al., 2020). Amongst proteins some milk proteins like casein and whey proteins are of certain value due to their optical properties and physical properties like water solubility and emulsifying ability Kandasamy et al. (2021) .

In this review article, recent advances in biopolymer (polysaccharide, protein and lipid) based biofilms have been discussed.

2. STRUCTURAL COMPONENTS OF EDIBLE FILMS

The main structural components through which the films can be produced include the biopolymers (proteins, lipids or polysaccharides), plasticizers, surfactants, crosslinking agents among other additives of choice. The physical and chemical properties of resulting film or coating significantly depends on the category of biopolymer used (Han, 2014).

2.1. Plasticizers

During the preparation of formulations for edible films and coatings production, plasticizers can be added to lessen the interaction or intermolecular forces among biopolymers. These interactions give the biopolymer a rigid and brittle structure (Ribeiro et al., 2021). Plasticizers are biodegradable, non volatile and non toxic (Mostafavi & Zaeim, 2020). Plasticizers are of two types based on their structural properties: internal plasticizers and external plasticizers. Internal plasticizers position themselves in between the polymer chains by co polymerization reaction to provide adequate space for polymer molecule's mobility and lessen their brittleness, while external plasticizers do not react chemically with the biopolymer but physically interact with the polymer to cause swelling (Sothornvit & Krochta, 2005). External plasticizers are liquid in nature, have a semi-rigid structure and have high flexibility. (Chaudhary et al., 2020). In edible films and coatings, especially for protein and polysaccharide based, one of the most common examples of plasticizer is water molecule, but it has a drawback that it can be easily dehydrated at low humidity. This is the reason that now a day's hydrophilic plasticizers are preferred as they will reduce water loss from the edible material by preventing dehydration (Han, 2014).

Among various plasticizers glycerol is the most accepted one, and it is applied to agar based films due to their structural similarities. Other carbohydrates based plasticizers are sugars (glucose, fructose and sucrose) and pylols like sorbitol, glycerol and polyethylene glycol can be used as food based plasticizers (Mostafavi & Zaeim, 2020). The reason why most of the plasticizers react with the polymer is they contain a hydroxyl group and this hydroxyl group forms the hydrogen bond with the biopolymer to decrease its brittleness and increase flexibility. Among lipid based plasticizers, waxes, fatty acids and lecithin oils top the list (Sothornvit & Krochta, 2005). The only drawback of plasticizers is that it affects the films permeability to aroma, moisture and gamses (Espitia et al., 2014). The composition of edible films and coatings is shown in fig 2 (Ribeiro et al., 2021).

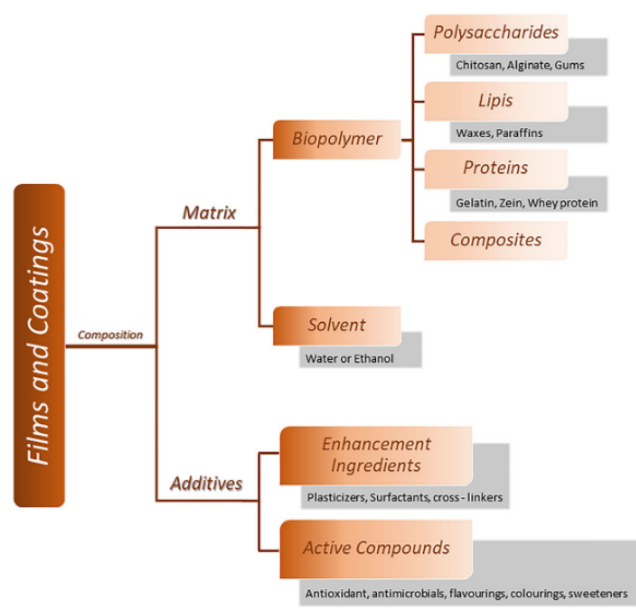

Figure 2. Composition of a typical edible film or coating

2.2. Cross linking agents

Cross linking agents are such agents that develop a covalent or a non covalent bond between polymer chains. These covalent or non-covalent bonds give three dimensional structures to the polymer molecules. The procedures through which a covalent bond is created among polymers are irradiation and sulfur vulcanization while, non-covalent bond is created by hydrogen bonding or ionic interactions (Chaudhary et al., 2020). Cross linking agent the edible films and coatings and lessen their permeability towards water and microbial agents. A cross linker tetraethoxysilane is mixed with chitosan and guar gum to produce edible films in 2017. Glutaraldehyde is often used as a cross linker in edible films to integrate water resistance and active compounds in films and coatings (Ribeiro et al., 2021). For starches, cross linking is a very crucial step as it improves the water holding capacity, viscosity and texture of the film.

2.3. Additives

Additives are added in edible films and coatings to incorporate the desired properties like anti browning, anti microbial or antioxidants. Additives are also used to imrove the rheological properties, enhance color, flavor and aroma and to add neutraceuticals to the films (Chaudhary et al., 2020). Neutraceuticals and pharmaceuticals are added in the films to make the resulted product a drug delivery agent (Han, 2014). In polymeric based edible films and coatings, nanomaterials are incorporated, which can introduce specific properties into film packaged product that is unattainable with blank films. Nanomaterials integrate the desired properties without distressing the transparency and permeability of the film (Chiralt et al., 2018).

3. TYPES OF EDIBLE FILMS

3.1. Polysaccharide based films and coatings

Polysaccharides are responsible for elevated solubility, tensile strength and elongation of the edible films and coatings due to their linear structure. Due to their linear structure they can form colorless and flexible films and coatings, as well as, contributing to lessening the oxidative rancidity and preventing the darkening of skin of fruits and vegetables. Polysaccharides based films have a well maintained chain of hydrogen bonding due to which they serve as a good barrier for gas and aroma (Luangapai et al., 2019).

3.1.1 Chitosan based films and coatings

Chitosan is a naturally occurring biopolymer and has exceptional film forming properties. Chitosin is obtained by the n-deacetylation of chitin. Its structure comprises of reactive groups like a primary reactive group (C-6), a secondary reactive group (C-3) and every repeat unit contains hydroxyl group with deacetylated units containing amino group. The etherification and esterification in chitosin occurs with the help of the hydroxyl groups (Badawy & Rabea, 2011). The biofilms made from chitosin have versatile and unique properties like biofilms have a stable structure, their matrix are homogeneous, and exhibit mechanical as well as water barrier properties. When chitosin is applied to fresh fruits and vegetables, it forms a continuous coating on its surface and this continuous coating has the desired thickness, viscosity and gas and water permeability (Badawy & Rabea, 2011) (Romanazzi et al., 2018). The nanoemulsions of chitosin are quite in demand because nanoemulsions give the base material or polymer a kinetically stable system (Aswathanarayan & Vittal, 2019a). The only drawback that chitosin based films and coatings exudes is their mechanical properties. This biopolymer based films and coatings have poor mechanical properties. Other biopolymers like starch, alginate and gelatin is used to evade this issue (Xu et al., 2020).

3.1.2 Alginate

Brown alga is a primary source of obtaining alginate and is composed of α-L-gluronate and β-D-monnuronate. Alginates are anionic in nature and due to this property they can be solubilized in water to form stable and transparent films and coatings (Anis et al., 2021). Films form from alginate have unique barrier against oils, fats, moisture and oxygen. The oxidation of food components can be prevented due to the oxygen barrier of alginate and the shrinkage of food components is prevented due to the barrier against moisture. Furthermore, the films based on this biopolymer have anti-microbial properties that helps increase the shelf life of the food product onto which it is applied (Nair et al., 2020). In the wake of all these barrier and hinder properties the alginate edible films and coating retain the flavor and color of the food product (Nair et al., 2020).

3.1.3 Exopolysaccharides from LAB

Exopolysaccharides are high molecular mass polymers that are secreted by lactic acid bacteria. They are long chain biopolymers and the long chains are formed by repeated sugar monomers. Exopolysaccharides are divided into two categories: the one which contains only one type of sugar monomers are homopolysaccharides and one which contains different types of sugar monomers are heteropolysaccharides (Moradi et al., 2021). The LAB is directly added to the food product, because their yield of EPS is relatively low, so, it is preferred to generate the EPS in situ (Xu et al., 2019). As the EPS is produced from LAB, it has an edge over other types of polysaccharides, because it is safe to use in the food industry (Saadat et al., 2019). Dextrans, levans, kafirens and haluronic acids are most commonly known EPS in recent times. The exopolysaccharides of LAB are used as an additive as well as structural component for edible films and coatings (Razavi et al., 2020). EPS from LAB are reported to produce antagonist action during in vitro conditions against harmful bacteria and generally microbes (Nehal et al., 2019). EPS usually targets the genetic material, cell wall and cytoplasmic membrane of bacteria. The basic reason of antimicrobial activity of EPS is that it can impair the cell division of bacteria (He et al., 2010). A LA producing F-mou strain of lactococcus lactis extract EPS that are effective against some pathogenic bacteria (Nehal et al., 2019).

Table 1
Polysaccharide based edible coatings and their main advantages

Coating material	Food product	Main advantage	
Yam starch	Strawberries	Reduce decay, weight loss and firmness	(Mali & Grossmann, 2003)
Gum Arabic	Anna apple	Reduce decay	(Mali & Grossmann, 2003)
Almond gum	Sweet cherries	Delay in changes in color, weight loss and firmness, decrease in respiration rate	(Mahfoudhi & Hamdi, 2015)
Gum Arabic	Strawberries	Inhibit fungal growth	(Ali et al., 2010; Tahir et al., 2018)
Gum Arabic	Tomatoes	Inhibit fungal growth	(Ali et al., 2010)
Potato peel waste with oregano essential oil	Salmons(cold smoked)	Reduce the growth of L.Monocytegenes.	(Tammineni et al., 2013)
Opantia cactus polysaccharides	Kinnow mandarin	Increase shelf life with regard to its pH, acidity and aroma.	(Riaz et al., 2021)
Cordia myxa gum	Artichoke bottoms	Delayed browning, shelf life extension.	(El-Mogy et al., 2020)
Arabic gum with aloe vera and garlic extract	Guava	Shelf life extension, higher ascorbic acid content, lower content of total sugars	(Anjum et al., 2020)
Gum Arabic with lemongrass and cinnamon essential oil	Banana and papaya	Antifungal effect, reduce the growth of colletotrichum musae.	(Maqbool et al., 2011)
Apricot gum containing setureja intermedia extract	Wild almond kernels	Lower fungal contamination, oxidative compound content and fatty acid profile variation.	(Hashemi & Raeisi, 2018)

3.1.4 *Starch films from novel Pachyrizus ahipa*

Among polysaccharides, starch is considered a promising material for the preparation of edible films and coatings due to its easy availability, its good film forming ability and performance (Wilhelm et al., 2003). Starch can be extracted from sources like cereal grains such as, wheat, corn and rice and tubers like potato and cassava. Pachyrhizus ahipa are starch rich tuberous roots and belongs to leguminous plants family (López & García, 2012).

3.2. Protein based edible films and coatings

Proteins are biopolymer macromolecules and can either be fibrous or globular. They are formed for edible film formation only when its polymeric chains denature and become elongates. This denaturation is done by using acids, bases or heating (Hassan et al., 2018). Once the protein chains denature, it becomes easy for them to interact with other neighbouring molecules. This strong interaction creates ionic, covalent and hydrogen bonds results in more compact films (Calva-Estrada et al., 2019; Hassan et al., 2018). The biopolymer protein is consider to be the best polymer for film and coating application because it imparts biodegradability, biocompatibility and good film forming properties to the coating or film forming solution (Gallego et al., 2016).

3.2.1 *Whey protein films*

Whey is the green yellowish colored liquid, soluble in water and is produced in the dairy industry when the casein is coagulated during cheese manufacture (Yadav et al., 2015). This dairy whey is used by food packaging industries to produce edible biofilms and coatings. Whey is an amalgamation of carbohydrate, lipid, lactic acids, minerals and protein (Karaca et al., 2019). Whey protein is composed of three protein structures: secondary tertiary and quaternary with diverse other bondings like sulfur bonding. These all structures make it heat labile, and difficult to phosphorylate (Kandasamy et al., 2021) . Whey protein is widely used as a film forming and coating agent due to its properties like film forming ability, acid stability and aeration characteristics (Krochta, 2002). Whey protein is extracted from milk by various techniques like gel filtration, ion exchange chromatography, ultrafiltration and electrodialysis to name some. In ultrafiltration the mineral content of whey is removed (Adegoke et al., 2021).

Generally the casting method is applied to generate the whey protein films on a desired shape and then is detached to be wrapped around the food product. The final film produced has a gel type rearrangement with a three dimensional structure (Kandasamy et al., 2021) . The resulted films or coatings are colorless, transparent and odorless. Whey protein has amphiphilic nature and also has electrostatic charges but it can easily be denatured (Karaca et al., 2019). Two techniques can be used for making edible biofilms and coatings from proteins: first is the wet process or solvent casting and second is the extrusion and compression moulding. The former method is applied to produce thin layer films and is a cost efficient method (Schmid & Müller, 2019). While in the extrusion or compression moulding procedure the films undergo a thermal compression moulding stage after their production (Henriques et al., 2016).

3.2.2 *Protein hydrolysates with active compounds*

The fragments of a protein that does not trigger by their precursor in the sequence but, by the proteolytic enzymes and normalize the physiological functions of the body by cooperating with receptors are called bioactive peptides. These bioactive peptides exhibit the antioxidant, antibacterial, anticoagulant, anti fungal, antiviral and antithrombotic characteristics. The criteria for proteins to be considered bioactive peptides is the frequency at which the bioactive component occurs in the protein sequence and the potential activity profile (Bhandari et al., 2020). The hydrolysis of food product by certain digestive enzymes which perform proteolytic activity can release the bioactive peptides of a protein. Other processes through which bioactive peptides are released are fermentation by microorganisms and also by the hydrolysis by enzymes in vitro (Lorenzo et al., 2018). Films and coatings produced by below mentioned methods have high brittleness and to increase the flexibility, plasticizers are added but they can negatively affect the film by increasing their permeability.

The other method use to increase the flexibility of the film is to reduce the molecular weight of the protein and this is done by protein hydrolysis. Films from whey protein hydrolysate show better oxygen permeability than the simple protein containing films (Sothornvit & Krochta, 2000). Protein hydrolysates along with the bioactive compounds can be added to yhe films to increase the shelf life of any food product (Tkaczewska, 2020).

3.3. Lipid based edible films and coatings

Lipids are hydrophopic compounds and are soluble in non-polar solvents. Due to the hydrophobic nature of lipid compounds the resultant films and coatings are thick in size and brittle. Hydrophobic nature is also a virtue in disguise as they are excellent water repellent so provide efficient water barrier to food products (Hassan et al., 2018). Lipids imparts bad taste and smell to the food product, and the resulted food product is delicate and obscure which is a huge drawback in their usage among consumers (Hassan et al., 2018).

3.3.1 Waxes and paraffins

When ethylene undergoes catalytic polymerization a mixture of hydrocarbons is obtained which include crude petroleum. After several distillation methods paraffin wax is extracted from crude petroleum. The application of paraffin waxes is mostly in dairy industry (cheese) and in fruit and vegetable industry. An example of paraffin wax is carnauba wax which was extracted from Copoernica Cerifera (palm tree leaves). Honey bees also gives bees wax. We obtained candellila wax from candellila plants. As the coatings and films are obtained from lipids are thick so it is necessary to dispose off the coating prior to eating the food product. If the coating is thin they are safe to eat. Paraffin wax coating and films is excellent barrier against water and provide moisture barrier to the food product. Lipid containing edible films and coatings are safer to use when applied in thin layers on the food product.

4. NANO ENCAPSULATION OF EDIBLE FILMS OR COATINGS

The edible film and coating mixture with active compounds when applied to the food product show some changes in the composition mixture of the edible coating and that is one limitation of this technology (Silva-Weiss et al., 2013). That is one reason the active compound cannot reach its target area and cannot interact with the edible coating (Han, 2014). This drawback is resolved by introducing the nanotechnology in the food industry that directs the active compound towards its target and that is the food material. The nanostructures used for this type of edible films and coatings are nanoemulsions, nanofibers, nanotubes, nanoliposomes and nanocomposites. These nano structures when combined with the biopolymer and active compounds, directs it to the target (Ozkan et al., 2019; Zambrano-Zaragoza et al., 2018). Along with the target direction nano encapsulation impart the controlled release of the active compound for food preservation or desired properties.

When these nano particles are incorporated with anti microbial compounds they help in preventing the microbial deterioration of food products. To prevent the harmful effects of oxygen or air deterioration on food product, antioxidants along with nanoparticles are incorporated in the coating emulsion. The antioxidants, when used in a larger amount, can impart strong flavor, color and odor which are some hurdle in this technology. When antioxidants are coated on nanoparticles, they can be used in small amounts and can prevent all these drawbacks (Lopez-Polo et al., 2020; Salah et al., 2020).

4.1. Nanoemulsions with edible coatings

Nanoemulsions are such mixtures that enhance the properties of the base coating material because of their stable colloidal properties. The composition of the nanoemulsion solution is based on the structure and composition of the base material and the procedure to prepare those emulsions. The colors, flavors, antimicrobials and coatings can be transferred in a controlled manner through these nanoemulsions Aswathanarayan and Vittal (2019b). To prepare these nanoemulsions two methods are adapted: high energy method and low energy method. In the high energy method, different mechanical machinery is used that separates the oil phase from the water phase and convert it into droplets which are nanosized. The main protocols that can be done to produce nanoemulsions are homogenization at high pressure, shear stirring at high speed, microfluidization and ultrasonication (Acevedo-Fani et al., 2017; Mahfoudhi et al., 2016). The composition of the solution used for creating droplets and temperature at which the procedure is done directly affects the droplet size and properties. High energy method for production of nanoemulsion is not commercially successful because they are not reported for targeted and controlled delivery of active ingredients like proteins, enzymes and nucleic acids in the food product. Furthermore this procedure is expensive because it requires trained manpower and costly equipment (Jasmina et al., 2017).

The low energy method does not require any expensive mechanical force or machinery that's why it is cost effective and fast occurring method for nanoemulsion preparation. The low energy mechanisms are used in this method like phase inversion temperature, spontaneous emulsification, and phase inversion composition (Borthakur et al., 2016; Dasgupta et al., 2019). The composition and properties of the matrix through which nanoemulsions are made can be changed by using these methods for droplet formation (Jasmina et al., 2017). Low energy method generally adopts the emulsification of matrix by using surfactants. This procedure separates the oil phase and make nanosized oil droplets (Borthakur et al., 2016). In low energy method the organic phase which is oil based is mixed with surfactant (Tween 20, 40, 60, 80 and 85) which is hydrophilic in nature. When the organic phase is mixed with surfactant, turbulence is generated, which ultimately produces tiny oil droplets (Chang et al., 2013).

4.2. Nanoliposomes with edible coatings

Nanoliposome is an emerging technique in nanobased edible coatings and films that can transport the active compound inside the food product in a controlled and targeted manner. As we now the use of nanoparticles can enhance the bioavailability and bioactivity of any material, so is the case with nanoliposomes Nair et al. (2020). The mixing of two technologies edible coating with nanoliposomes promises better anti microbial, anti fungal, anti browning and vitamin enriched food product with extended shelf life Nair et al. (2020). Some nanoliposomes have recently been reported to provide antioxidant properties in edible coatings. One of these which is reported is a cellulose based coating with quercetin or rutin encapsulated inside nanoliposome that controls the release of polyphenols (Lopez-Polo et al., 2020; Silva-Weiss et al., 2018).

Nanoliposomes can encapsulate essential oils, because if essential oils are used directly with the edible coating, they emit strong taste and smell, which is a drawback of using it as an active compound. Furthermore, essential oils are highly unstable and volatile Nair et al. (2020). A sausage sample was reported to be packed inside a chitosin based edible coating with garlic essential oil encapsulated inside nanoliposome that degrade certain decomposing bacterial species (Esmaeili et al., 2020). Another example of antimicrobial activity of essential oil based edible coating is the gelatin based coating with nanoliposome encapsulating cinnamon essential oil. Nanoliposome can protect the cinnamonaldehyde of cinnamon essential oil due to its structural properties. The nanoliposome can result in the controlled and targeted release of the antimicrobial agents in the food product (Wu et al., 2015). The liposomes can increase in size if they are stored for a long period of time , so it is necessary to coat a layer of the biopolymer compound on the nanoliposome which can prevent it from breaking (Lopez-Polo et al., 2020; Madrigal-Carballo et al., 2010).

5. PRODUCTION METHODS FOR EDIBLE FILMS AND COATINGS

The production process of edible films and coatings require certain physicochemical changes in the edible biopolymer to make films and coatings that impart proper structural and environmental protection to food product. During production the phase change or precipitation of the biopolymer is important and it is done by simple coacervation (addition of electrolyte and a non-electrolyte to regulate pH and impart crosslinking), complex coacervation (two hydrocolloid solutions are mixed and both have opposite charges) or gelation (thermal coagulation by heating or cooling) Parreidt, Müller, and Schmid (2018). In the beginning of the process the biopolymer (polysaccharide, protein or lipid) is dissolved in water or alcohol (in some cases the solution of both) and then the bioactive agents like antimicrobials, antioxidants, antifungals or colorants are added to impart desired properties to the film or coating (Ganiari et al., 2017), (Hassan et al., 2018).

5.1. Edible films production

Techniques used for the preparation of synthetic plastics are adapted to make edible films. There are three major steps used for its production: firstly the biopolymer is stabilized in its wild form, after that, the polymer chains are arranged and then these arranged polymer chains are subjected to form bonds to create a three dimensional network of a film. This all phenomenon is done by two techniques solvent casting and extrusion. The later one is a wet technique and the former one is a dry process and is generally environment friendly due to the negligible use of solvent in its composition (Calva-Estrada et al., 2019; Murrieta-Martínez et al., 2018).

5.1.1 Solvent casting

In the laboratory scale production of edible films, the solvent casting method is implied which generally comprise of spreading the biopolymer solution on the base material of desired shape and subsequently air drying the material in an oven to form a consistent film. After the drying is done the film is peeled off from the base material (Dhumal & Sarkar, 2018; Parreidt, Müller, & Schmid, 2018). This peeling of the film from the base material is a critical step and often results in the wrinkling or tearing of the film and it creates limitations in applying this technique in the laboratory. The correct choice of the base material can minimize the risk of tearing and wrinkling of the film (Dhumal & Sarkar, 2018). The physical condition of the environment in which solvent casting is done should be controlled, like temperature and relative humidity should be checked to prevent the sudden drying of the casting solution. The final physical and chemical properties of the film highly depend on the controlled parameters, composition of the biopolymer solution and thickness of the film (Parreidt, Schmid, & Müller, 2018). Two different studies in 2016 and 2019 reveals the application of solvent casting method by producing cassava starch films and sago starch with guar gum films (Dhumal et al., 2019; Medina-Jaramillo et al., 2017).

5.1.2 Extrusion

In this technique the film forming biopolymer solution containing added plasticizer is heated at the temperature above its glass transition temperature. The water content in this

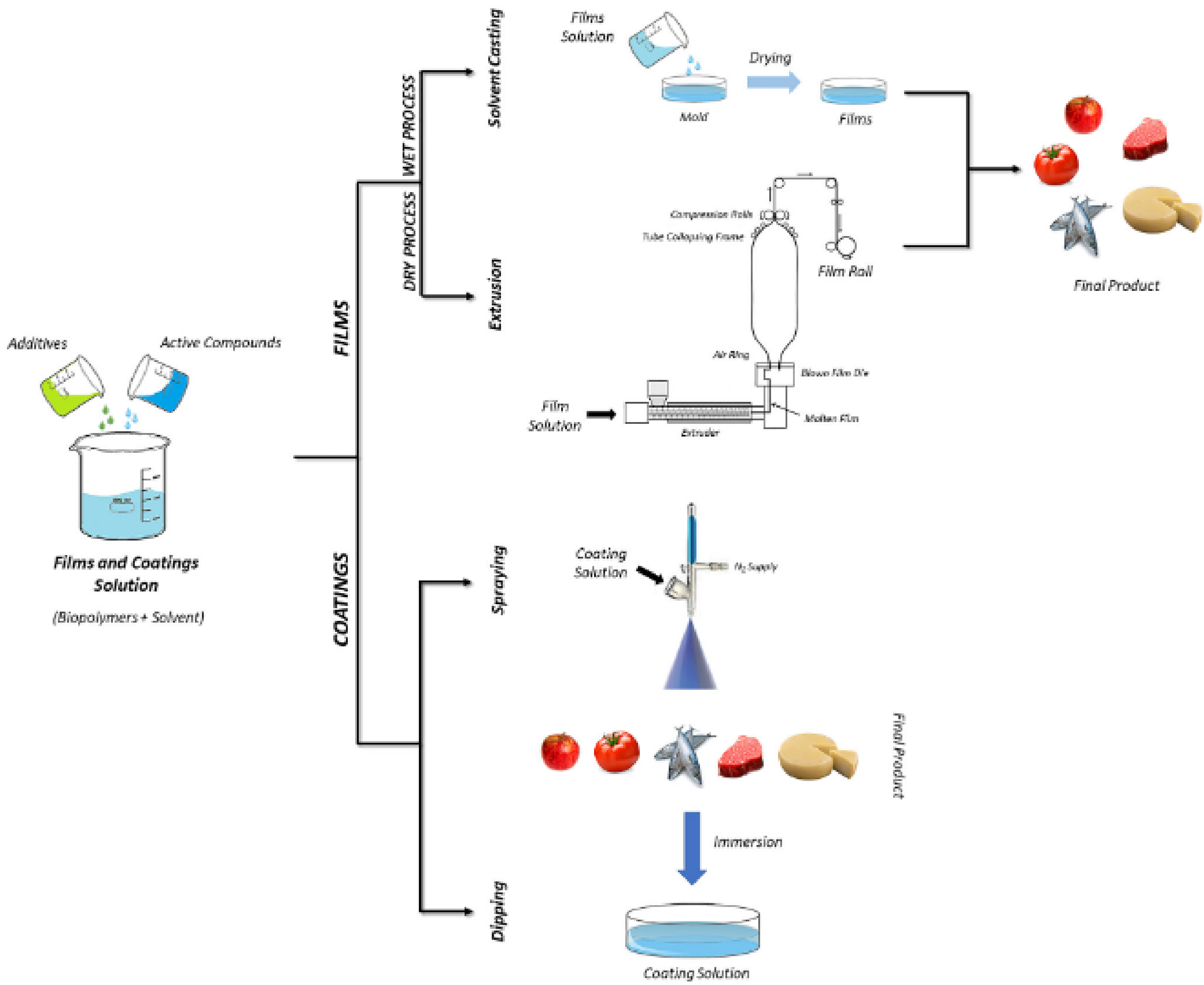

Figure 3. Production methods of edible films and coatings

technique is kept low and the thermoplastic properties of the biopolymer helps in this technique (Murrieta-Martínez et al., 2018; Parreidt, Müller, & Schmid, 2018). This technique requires less amount of solvent and thus the evaporation procedure does not take too long to occur. That's why this technique is feasible for commercial as well as laboratory scale production Parreidt, Müller, and Schmid (2018). A study reveals the production of films by this technique by mixing wax and casein with the addition of potassium sorbate by using twin screw extruder. By using this technique the films antimicrobial, tensile and barrier properties enhanced (Chevalier et al., 2018).

5.2. Edible coating production

Edible coating is directly applied to the food product and is analysed on the basis of the ability of the coating material to adhere to the food product Parreidt, Müller, and Schmid (2018) . To prevent the food product from deterioration or preventing air suffocation, thickness of the coating should be controlled (Dhumal & Sarkar, 2018). There are three methods through which edible coating is applied on the food product: dipping, spraying and spreading.

5.2.1 Spraying

This method uses the phenomenon of droplet spraying on the targeted product that forms a semi permeable membrane of the coating material on the food product. The physicochemical properties like density, viscosity and surface tension of the biopolymer material, along with the operating conditions (temperature and air pressure) usually determines the characteristics and properties of the coating. The main advantage of using this technique is its cost efficiency which can be achieved due to its application to large surface area materials, control of temperature, and its hinderance to any kind of contamination Parreidt, Müller, and Schmid (2018). Besides, the coating formed due to spraying technique is less than 20 μm in width and controls the thickness of the coating (Dhumal & Sarkar, 2018).

5.2.2 Dipping

Dipping is a technique in which the product is immersed in the coating solution and it occurs in four steps including two immersion cycles. In the first step the food product is immersed or dipped in the biopolymer solution. In second step the biopolymer solution is placed in the cross linking bath and the material to be coated is placed in that bath. The solution is drained at regular intervals or after each stage Parreidt, Müller, and Schmid (2018) . Contrary to the spraying method this method generates a thick coating on the food product. This property is controlled by determining the density, viscosity and surface tension of the biopolymer solution used. This technique is generally applied on the food that is minimally processed (Dhumal & Sarkar, 2018).

5.2.3 Vacuum impregnation

Vitamins and minerals are the primary source of energy for the body and to enrich the food product with vaitamins and minerals the method of vacuum impregnation is used. The fruits and vegetables that are porous in their outer side and entrap air in their pores can be vacuum impregnated with solutes and can form much thicker films Parreidt, Müller, and Schmid (2018). The steps for the vacuum impregnation are same as dipping process with the difference in using vacuum chambers instead of the dipping tanks. The food product is kept in the coating solution after its application and after some the process of atmospheric restoration is applied on the product. Atmospheric restoration and the pressure of vacuum chambers are critical for the even application of the coating material Parreidt, Schmid, and Müller (2018) .

6. APPLICATIONS IN FOOD INDUSTRY

Some properties are taken into consideration to apply edible films and coatings to the food product. These properties include barrier properties, optical and chemical properties, mechanical and structural properties and cost and availability of the packaged coating or film Parreidt, Schmid, and Müller (2018) . Some food products on which edible films and coatings are applied are fruits and vegetables, seafood and meat and dairy products.

6.1. Fruits and vegetables

As the world is progressing, people are becoming health conscious and demanding the food that is rich in vitamins, minerals and nutrients (Hassan et al., 2018; Parreidt, Müller, & Schmid, 2018). The inclusion of such dietary materials can help to prevent severe diseases of heart, lungs and neurodegenerative diseases. These all minerals and vitamins can be obtained from fruits and vegetables (Hassan et al., 2018). But during transportation and while storage the fruits and vegetables lose their moisture and nutritional value. According to a study about 30% of the fruits and vegetables become infected by microorganisms or insects during storage and harvesting. Once the product got infected and expose to the environment, it become more vulnerable to shorter shelf life, early browning and physiological changes (Hassan et al., 2018; Parreidt, Müller, & Schmid, 2018). Edible films and coatings diminish all these shortcomings associated with the non edible film packaged food product. Edible films and coatings not only increase the shelf life of the food product but also add nutrients and bioactive components to prevent it from the surrounding and increasing its nutritional value (Hassan et al., 2018).

Any fruit or vegetable is far more protected when it is intact. But for fresh cut fruits and vegetables the prevention process is far more tricky then the whole fruit itself. The barriers like skin, cuticle and rind protect the food product from natural invaders like microbes and insects but when the skin is removed to cut the food product it became susceptible to microbes (Baldwin, 1994; Rosario et al., 1995). The fruit and vegetables that are prepared from conventional technique also called minimally processed food are subjected to various methods that can cause harm and wounds on the food product. That food become more vulnerable to microbes, browning and there will be possibility of it to lose color, texture and flavor Parreidt, Müller, and Schmid (2018) . This spoilage of food material is prevented by edible film or coatings that also add natural or artificial barrier against microbes, increase shelf life, prevents browning and give a barrier for oxygen and aroma Parreidt, Müller, and Schmid (2018).

6.2. Meat industry

The meat industry is subjected to many deteriorative changes in the meat products during its storage due to some enzymatic processes that take place in it (Dhumal & Sarkar, 2018). If the meat is contaminated with pathogenic microbes, which is very common in seafood, the final product looks brown in color, have bad texture and lose the unique meat juice. This ultimately results in food borne diseases in humans and generally other consumers (Dhumal & Sarkar, 2018). As the meat product are of shorter shelf life the edible films and coatings play a vital role in keeping the meat and seafood products prevented from microbes and other contaminants. Frozen tambaqui fillets are coated with chitosin based edible films conjugated with clove essential oil, which resulted in prevention of their deterioration from external chemicals and microbes (Vieira et al., 2019). Another edible film which was sodium alginate conjugated with olive leaf extract and hazelnut skin was reported to protect the chicken nuggets from lipid oxidation and resultantly increasing the shelf life (Ozvural, 2019).

7. CURRENT TRENDS AND FUTURE CHALLENGES

In recent times, there is a vast research on the use of natural sources like plants and animal's biota to incorporate additive like anti microbials, antifungals and anti browning agents in the food product with edible films and coatings (Ribeiro et al., 2021). Recently, the use of nanotechnology to encapsulate the functional ingredients is increasing because it improves the mechanical properties of the films which is another milestone in edible films and coatings research (Jeevahan & Chandrasekaran, 2019). Another main concern is the extraction of polysaccharides and proteins from plants and animals, because its extraction requires professional handling and expensive procedures. This problem is solved recently by extracting these biopolymers from microbes that are easy to handle and easily available (Hassan et al., 2018). Among biopolymers chitosin is an easily available biopolymer and has found vast applications in packaging industries. An edible insect named Tenebrio molitor produces chitin as a waste product during its growth and chitin is a major source of chitosin, so it can be obtained from it by low cost procedures (Li et al., 2019).

The trend of incorporating active ingredients in the edible film or coating is becoming popular these days because it elevates the nutritional properties of the food product along with increasing its shelf life. For further research there is a need to identify natural sources for extracting biopolymers from plants and animals that have innate antimicrobial and antioxidant ability (Ribeiro et al., 2021). The future research should be based on finding the inherent mechanical properties of the films and coatings as well as their toxicity and environmental effects in order to commercialize and industrialize them (Mkandawire & Aryee, 2018). Another problem is the strong water permeability of the edible films or coatings as compared to the synthetic plastic packaging which affects the flexibility of the films and it needs to be overcome. This problem is partially solved by adding plasticizers and hydrophobic materials like oils in the film formulation to improve barrier properties (Çakmak et al., 2020).

For building the trust of people in consuming the edible films and coatings several tests should be done after their production to ensure the biocompatibility of these films with the human body. Tests after edibility should also be done to ensure the biodegradability of the films inside human body (Jeevahan & Chandrasekaran, 2019). Another evident problem with the delay in its commercialization is the lack of information among consumers about edible films and coatings. One main reason of this is precise research in this field and the high cost of these packaging materials as compared to the plastic packages (Jeevahan & Chandrasekaran, 2019). In future, these all drawbacks should be minimized with more research on this subject for early commercialization of these films and coatings.

8. CONCLUSION

With the increase in environmental awareness and healthy lifestyle among public, people are demanding the food products that are environment friendly and have basic health related ingredients like vitamins, minerals and anti microbials in the food product. These requirements are fulfilled by edible films and coatings that are environment friendly, can be made in low cost by using edible biopolymers and have additives for healthy lifestyle. Recently research has been made to incorporate functional ingredients that provide safety to the food product, and also incorporate anti microbials and anti fungals in the food product. Now the main challenge is to synthesize films that have superior functional and physical properties because that is one quality that needs extensive research to totally wipe off the plastic packages. For the commercialization of edible films and coatings, the main work needs to be done is on the improvement of mechanical and physical properties of the films and coatings to ease its industrialization.

CONFLICTS OF INTEREST

None to declare.

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AUTHOR CONTRIBUTIONS

MW, KA- Research concept and design, MW , KA- Collection and/or assembly of data, MW, KA - Data analysis and interpretation, KA - Writing the article, MW, HRM, KA - Critical revision of the article. All authors has approved the final version of the article.

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