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Chapter

A Study on Edible Polymer Films for Food Packaging Industry: Current Scenario and Advancements

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Abstract

Over the past two decades, food packaging and packaging industry have paid close attention to create biodegradable and edible polymer films and coatings. In a broad way, edible polymers emerged as a new class of materials that garnered significant properties due to their advantages over synthetic petroleum-based films. When compared to conventional packaging materials, edible polymer films can fundamentally simplify products, improving their potential to be recycled. This work aims to give readers a thorough introduction to edible polymer films, by discussing present research trends, classification, functionality and composition, fabrication, and characterization. The work also emphasizes the advantages and disadvantages of edible polymer films based on meat, poultry, dairy products, fruits, nuts, and vegetables.

Keywords: edible polymer, coatings, food packaging, antimicrobial, functionality, applications

1. Introduction

Many efforts have been made to create eco-friendly packaging material in response to the challenges caused by plastic waste in the packaging business. Food packaging is critical for storing foods, protecting them from infection, and maintaining food quality throughout the packaging-to-consumption process [1]. Several types of plastics are being used as packaging material due to their low cost, high performance, and easy production. Almost half of the packaging materials used in single-use throwaway applications, particularly food packaging, are produced from petrochemical polymers, such as plastics [2]. However, petrochemical plastics have a number of drawbacks, including environmental challenges, health dangers, and poor food quality due to their non-biodegradability [3, 4]. Also, production and consumption of plastics in the last few decades has put enormous stress on the environment by releasing plastic waste. Thus, there is a need to look for alternative packaging materials that should not

impose any problems, renewable, disposable, recyclable, and easily degradable [5]. A thin coating that covers the food surface is known as an edible package.

The growing demand for high-quality products with a long shelf life has led to the development of new processing technologies that guarantee natural qualities and appearance. As a result, the packaging industry as well as a number of young researchers are attempting to develop edible polymer films as biodegradable packaging materials [6]. In this case, edible polymer films would be an excellent choice for packaging. Edible polymers can be taken whole or in part by humans and lower animals through the oral cavity, with no negative health effects. Many advantageous properties, such as non-pollutant products, since they contain natural and biodegradable components generated from both natural and manmade materials are considered. Edible polymers have emerged as a suitable candidate for food packaging applications and have received significant attention in recent years [7]. The requirements imposed on edible polymer films were exclusively based on the product's specific qualities and changes in those attributes throughout production and storage [8]. Edible polymers have the ability to expand organoleptic properties of packaged foods materials. As the author reported, edible polymer has properties, such as flavorings, colorings, and sweeteners. Natural polymers and food-grade additives have become increasingly popular in the medical and food industries. Polysaccharides, proteins, and lipids, as well as plasticizers and surfactants, can be used to make these edible polymers. The ability of edible polymers is primarily determined by their barrier, mechanical, and color properties, which are influenced by the film composition and production procedure.

2. Edible polymer films: present research trends

In recent years, the use of edible films made from natural polymers and food-grade additives has steadily increased. Various materials, including polysaccharides, proteins, lipids, and resins, can be used to make these films, either with or without the inclusion of other ingredients (e.g., plasticizers and surfactants) [9, 10]. The moisture barrier performance of polysaccharide-based films is typically subpar, but they exhibit selective O₂ and CO₂ permeability and oil resistance [11]. Edible films can be fabricated based on cellulose, starch (natural and modified), pectin, seaweed extracts (alginates, carrageenan, and agar), gums (acacia, tragacanth, and guar), pullulan, and chitosan [12]. Films are made harder, crisper, more compact, viscous, sticky, and capable of producing gels; thanks to these substances. Other significant sources of polysaccharide-based biomaterials have been regarded as marine creatures, such as seaweed, bacteria, and microalgae [13, 14]. Moreover, edible polymers needed to meet a variety of requirements in order to be used as packaging and food components, including high barrier and mechanical efficiency, biochemical, physicochemical, and microbiological stabilities, as well as being nontoxic, nonpolluting, and inexpensive [15]. An emerging area of study in material science is the inclusion of active compounds derived from industrial wastes into edible films. Furthermore, inclusion of active components derived from industrial wastes become a hot area in materials research [16]. It was discovered that edible films may operate as transporters of active substances, such as antioxidants, antimicrobials, and texture enhancers [17], and many methods of obtaining them have been published.

In the past several years, the food industry has employed a lot of edible films made from polysaccharides (cellulose, starch, pectin, seaweed, gums, chitosan, and

pullulan), but lignocellulosic materials have just recently been shown to be viable for making edible films. Authors Slavutsky and Bertuzzi have reported starch films reinforced with cellulose nanocrystals derived from sugarcane bagasse [18]. In addition, Shimokawa et al. used hemicellulose fractions from *Pinus densiflora* leaves to create translucent and transparent films [19]. The compounds these authors obtained have high promise as edible films and characteristics resembling those of xylan. By using acid hydrolysis to separate crystalline cellulose nanofibrils from cotton linter, composite films with pronounced improvements in optical and mechanical properties, water vapor barrier qualities, and thermal stability were created [20]. Alginate-carbohydrate solutions containing 5% alginate and 0.5% pectin, carrageenan (or), potato starch (modified or unmodified), gellan gum, or cellulose were used to make composite alginate films (cellulose extracted from soybean chaff or commercial cellulose) [21]. With the alginate matrix, all of those carbohydrates were able to create composite films. However, using the cellulose from soybean chaff could result in composite films or casings made of alginate that have mechanical properties comparable to those of microcrystalline cellulose used in commercial products. **Table 1** represents the various edible films prepared using polymer and essential oils and other components.

Industry research futures (MRFR) predicts that the edible packaging market (based on protein, lipids, polysaccharides, and others) would be worth USD 2.14 billion by 2030, up from USD 783,32 million in 2021, with a compound annual growth rate (CAGR) of 6.79 percent (2022–2030). Throughout the projection period,

Matrix Polymer	Essential Oil Used	Targeted Product	Film Formation Method	Observations and Remarks	Reference
Carboxymethyl chitosan: Pullulan	Galangal essential oil (GEO)	Mango	Casting	Developed film exhibited excellent thermal stability, biodegradability and mechanical properties and was able to provide good preservation effect on mango.	[22]
Gelatin–chitosan blend	Ferulago angulate essential oil (FAEO)	Turkey meat	Casting	FAEO incorporated gelatin-chitosan blend film improved the water solubility and WVP. Increased anti-microbial property of the film helped in enhancing the shelf life of turkey meat.	[23]
Millet starch	Clove essential oil		Casting	Inclusion of clove oil enhanced the anti-oxidant activity and antimicrobial properties of the film.	[24]
SPI-gum acacia conjugates	Oregano essential oil (OG-EO), lemon essential oil (LM-EO), fruit of <i>Amomum tsaoko</i> Crevost et Lemaire (ACL-EO) and/or grapefruit essential oil (GF-EO)		Casting	GF-EO contained film exhibited better WVP, mechanical properties and glass transition temperature than other EO containing films. However, radical scavenging activity and antimicrobial activity was superior for LM-EO incorporated films.	[25]

Matrix Polymer	Essential Oil Used	Targeted Product	Film Formation Method	Observations and Remarks	Reference
Basil seed gum	Oregano essential oil		Casting	The resulting film showed a significant reduction in WVP with antimicrobial and antioxidant activity.	[26]
SPI:Acetem: Tween 60	Carvacrol and cinnamaldehyde		Casting	The addition of emulsions significantly reduced the tensile strength of the films and improved their EAB. An only slight improvement is reported with the addition of essential oils	[27]
Gelatin: MMT	Ginger essential oil (GEO)		Casting	Synergetic effect of GEO with MMT significantly improved the mechanical properties like EAB, puncture force, and puncture deformation.	[28]
Zein	Zataria multiflora Boiss. essential oil (ZEO)	Minced meat	Casting	Addition of ZEO along with monolaurin significantly improved the antioxidant activity and antimicrobial properties against <i>Listeria monocytogenes</i> and <i>E.coli</i>	[29]
WPI	Almond and walnut oils		Casting	Addition of oils increased the opacity of the film whereas swelling, water vapor permeability, and surface hydrophilicity were reduced.	[30]
Chitosan:MMT	Rosemary essential oil and ginger essential oil	fresh poultry meat	Casting	Incorporation EOs improved only the barrier to oxidation but not the antimicrobial properties. Overall performance of EOs in Chitosan/MMT film is not significant	[31]

Table 1. Various edible polymer films, fabrication techniques observed remarks.

north America will dominate the edible packaging market, followed by the United Kingdom, Japan, Indonesia, and Israel [32]. In order to enable their commercial implementation, researchers have been working nonstop for the past three decades to create edible films that can compete with traditional plastic films. Meanwhile, the packaging sector faces challenges in the areas of high moisture content, high pressure and modified atmosphere, natural and fresh goods, among others, and with an environmentally friendly approach [33].

3. Classification

Films and coatings are made from edible polymers and material composition, as well as the material thickness, differs between the two. Bags, pouches, capsules,

and casings are all made with films. Coatings are also applied directly to the surface of the meal. Hydrocolloids, lipids, and their composites are the three types of edible polymers. Hydrocolloids are long-chain hydrophilic polymers. The texture (chewy or creamy, lengthy or spreadable, and elastic or brittle) and sensory qualities (taste, mouth feel, and opacity) of the gel vary depending on the kind of hydrocolloid. Because of its hydrophilic feature, it can create viscous dispersion or gels in water. This is because the hydrocolloid's hydroxyl group bonds with water molecules, thickening the water or forming gels. They are weak water barriers because they can capture or immobilize water molecules in a three-dimensional network.

Fatty acids containing carbon atoms [34–38] generated from vegetable oils and waxes make up the other family of lipids [3]. They are generally opaque, waxy tasting, and slippery, and can be used to adjust color, flavor, sweetener, and salt concentrations, among other things [39]. Lipids are hydrophobic by nature, making them effective water vapor barriers with minimal permeability. The water permeability of edible composites made of hydrophilic hydrocolloids and hydrophobic lipids can be enhanced by combining them.

Based on their main components, edible films and coatings are divided into different categories. There are four major categories of edible coatings and films, including polysaccharides, proteins, lipids, composites, and polymers. **Figure 1** summarizes the classifications of edible films fabricated from various materials [40].

3.1 Polysaccharide-based edible films

The most prevalent natural polymer is polysaccharide, and in recent years, it has been frequently employed to create edible films or coatings. It is well known that polysaccharides contain a strong oxygen barrier and sites for the creation of hydrogen bonds, which can be exploited to incorporate functional ingredients including taste, coloring, and antioxidant compounds. These materials lack effective water

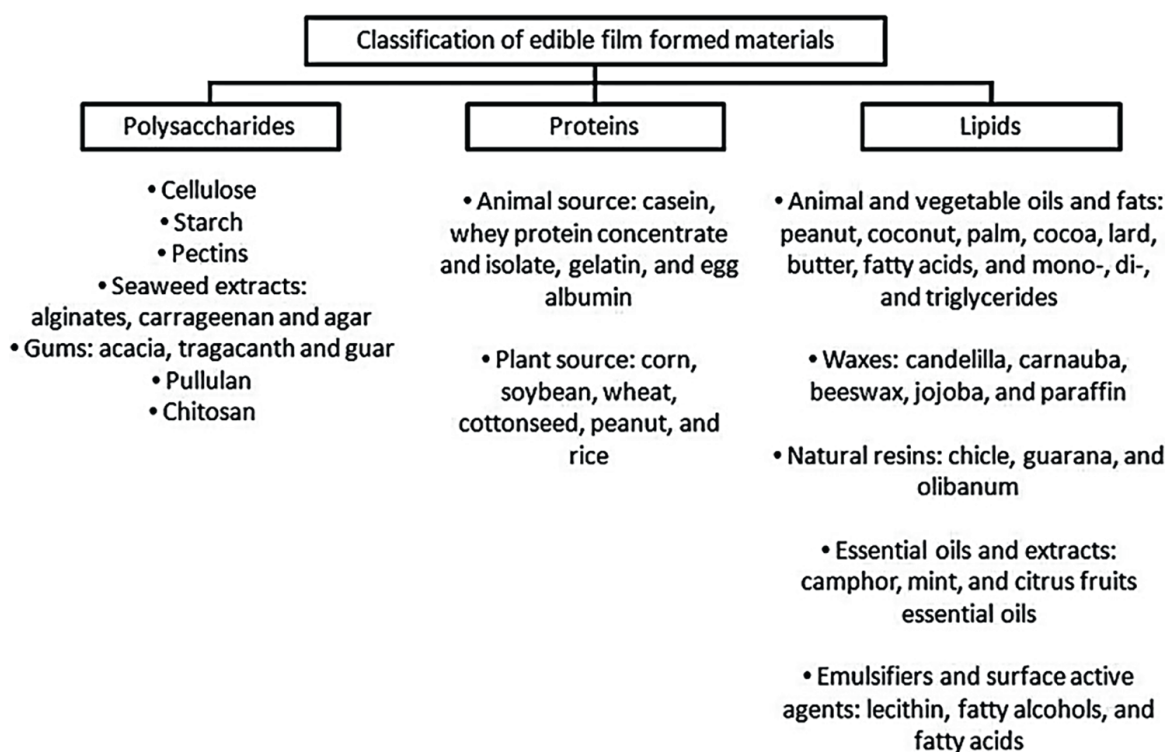


Figure 1.
Classification of edible films [40].

vapor barriers, however, this problem can be solved by combining them with other hydrophobic macromolecules, such as lipids [41, 42]. Natural-based packaging has been created using polysaccharides [43]. Edible films and coatings are created using polysaccharides, including starch, pectin, cellulose, exudate gums, and seaweed extracts. After considering their suitability in terms of the physical, mechanical, and functional characteristics of edible films and coatings, these substances are chosen. Although polysaccharide-based films and coatings have poor moisture barrier qualities, they are only slightly more permeable to oxygen and selectively permeable to oxygen (O₂) and carbon dioxide (CO₂) than other materials. Because they can alter the atmosphere inside the product, they are useful for the preservation of fruits and vegetables where they can lower the respiration rate. Pea starch-based edible films improved the use of pea starch in both food and non-food applications when guar gum and glycerol were added [44]. Edible films made of polysaccharides have a well-organized hydrogen-bonded network, which makes them effective oxygen blockers. Polysaccharide coatings are used to enhance the shelf life of products without causing any anaerobic conditions. They are colorless, free of oil, and have no oil content [41]. One can prepare the polysaccharide-based film either wetly or dryly. Several authors created polysaccharide-based edible films and coatings. Author Arantzazu Valdes et al. have created the natural pectin polysaccharides as edible coatings to improve organoleptic and nutritional characteristics and extend shelf-life [45]. Author Aarushi et al. has prepared Seaweed polysaccharide-based edible coatings and films. Authors emphasized the structure, extraction, and gelling mechanism of the alginate and carrageenan with incorporation of additives, such as plasticizers, nutraceuticals, flavors, and surfactants in the films [46]. Also, Prerna Singh et al. have prepared starch-based edible films with the objective of standardizing the production methodology and formulation for the creation of starch-based biodegradable antimicrobial films to increase the shelf-life of food and food items [47]. Similarly, author Poonam Singh et al. have developed cellulose-based films cross-linked with citric acid for probiotic entrapment. Authors concluded the probiotic bacteria were successfully entrapped into the films with acceptable viability [48]. All of these properties of polysaccharide coatings and edible films can extend fruit shelf life [41]. Alginate is a polymer found in brown algae (Phaeophyceae). Alginate consist of α -L-guluronate (G) and R-D-mannuronate (M) links in th (1–4) chain [41, 49]. Pullulan, a polysaccharide with microbial qualities comprised of maltotriose and (1,6) glycosidic units generated by *Aureobasidium pullulans* from starch [10], is another polymer with microbial features. Pullulan is a water-soluble, colorless, odorless, and tasteless edible film that is also oil permeable and heat sealable [41].

3.2 Protein-based edible films

In recent years, protein-based edible films have drawn interest due to their advantages over synthetic films, including their usage as edible packaging materials. Furthermore, protein-based edible films can be utilized for the individual packaging of tiny amounts of food, particularly goods that are not currently wrapped individually for practical reasons, such as beans, almonds, and cashew nuts. In addition, protein-based edible films can be used at the interfaces between different layers of components inside diverse diets. Moreover, protein-based edible films can be used to transport antibacterial and antioxidant compounds. In order to better protect and confine the food matrix, many young researchers began to examine and produce

nanostructured antibacterial edible coatings [28]. Protein-based packages can be active because the contact of the packaging with the packed food or the surrounding environment activates it. For illustrate **Figure 2** depicts the various materials and technologies that improve the value of food packages with protein [50]. Having a look at antioxidant and antibacterial compounds, which are most often employed components in the production of an active film or coating. The major goals of the active packages are to delay oxidation (by binding pro-oxidation substances or releasing antioxidants) and to limit pathogen development (organic acids, negatively charged phosphate groups, essential oils, anthocyanins, and chitosan) [51, 52]. Chemical, biochemical, or biological changes on the product's surface activate the release of active substances, ensuring a longer freshness and shelf life. Many significant protein sources may be found in a variety of vegetable and animal sources. Because of the abundance of resources in these fundamental goods, researchers began to extract polypeptides from a wide range of vegetable and animal products or by-products [53, 54]. Many authors prepared protein-based edible films for effective packaging material. Among them, Seung YongCho et al. have prepared oxygen barrier bilayer film pouches from cron zein and soya protein isolate for olive oil packaging for use with instant noodles [55]. Authors Burcu Gokkaya Erdem and Sevim Kaya have prepared edible film by freeze-drying from whey protein isolate and sunflower oil and evaluated functional properties of the films. Authors noticed that oil incorporation into the film matrix has decreased lipid droplet size and increased opacity [56]. Another author Nevena Hromis et al. have investigated possible application of edible pumpkin oil cake film as pouches for flaxseed oil protection. Author concluded that PuOC-based pouches present good protection for flaxseed oil [57]. Similarly, Long-Feng Wang and Jong-Whan Rhim have fabricated and studied the applications of agar/alginate/collagen ternary blend functional food packaging films. Authors noticed that ternary blend films exhibited good antifogging properties as well active packaging materials for highly respiring fresh agricultural products [58]. In

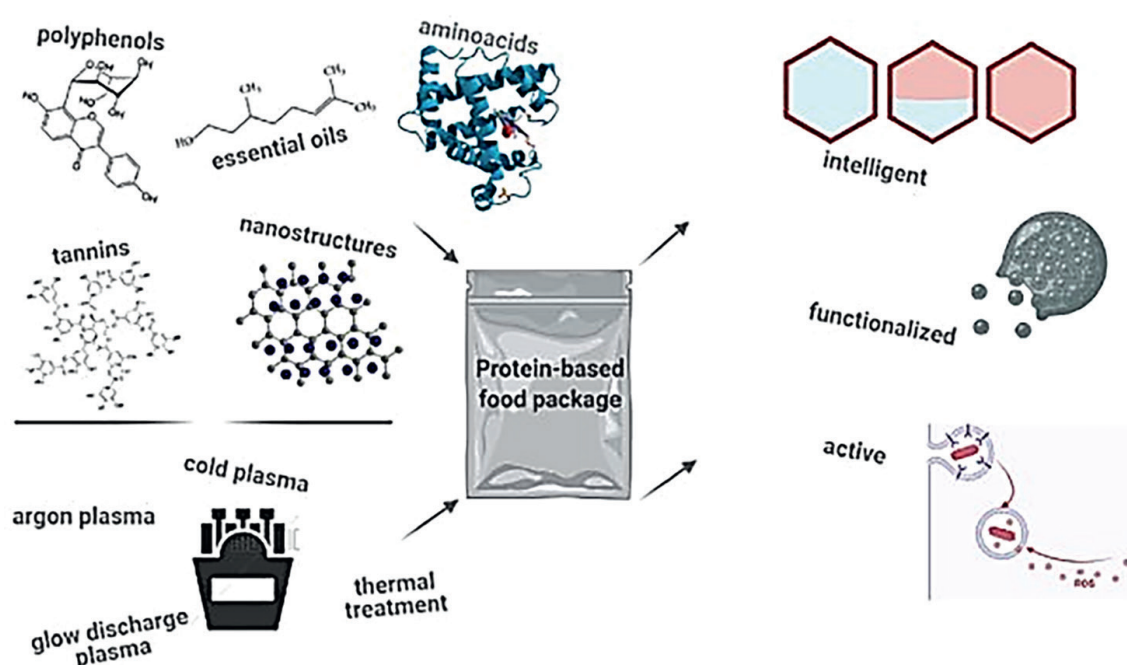


Figure 2. Materials and technologies that improve the value of food packages with protein [50].

continuation of protein edible films, author Jose Maria Lagaron et al. successfully produced a bio-composite material by melting compounding polyhydroxyalkanoates with a keratin component generated from poultry feathers [59]. Also, Moreira, Maria del Rosario et al. have investigated the antimicrobial property of bioactive packaging material prepared from edible chitosan and casein polymers for carrot, cheese, and salami [60]. Also, Xinyu Liu et al. have conducted the review on Site-selective protein modification with polymers for advanced biomedical applications. Author tried to elaborate current achievements in site-selective protein modification with polymers into five sections: site-selective protein modification; site-selective polymer modification; site-selective in situ generations of polymers from proteins; polymer biosafety; and biomedical applications [61]. Farhan et al. claim that a water extract from the germination of fenugreek seeds may be used to create an edible film of semi-refined-carrageenan. This edible film can be utilized as an alternative to standard plastic films used in the packaging of chicken flesh for fresh chicken breast [62, 63]. Meanwhile, Furcellaran, a genus of red algae, is one of the most important carrageenan sources. Jamróz et al. combined furcellaeon with nanofillers, maghemite nanoparticles, and graphene oxide to produce a film with strong antibacterial activity (for the nanofillers) but not exceptional mechanical qualities [64]. Author prepared *Syzygium cumini* leaves extract doped PVA and PVA/chitosan blend films for food packaging applications. The authors attempted to investigate the physicochemical characteristics of created blend films using XRD, SEM, AFM, FTIR, TGA, and UTM, as well as the films' antimicrobial capabilities. They determined that produced mixes might be used in packaging materials to extend food shelf life (**Figure 2**) [65].

3.3 Lipid-based edible films

Lipids are organic substances that come from living things including plants, animals, and insects. The presence of phospholipids, phosphatides, mono-, di-, and triglycerides, terpenes, cerebrosides, fatty alcohols, and fatty acids make up the variety of lipid functional groups [66, 67]. Lipids in coatings and edible film offer a variety of benefits, including gloss, the reduction of moisture loss, lower costs, and less complicated packaging [68]. For making lipid-based edible films and coatings more hydrophobic, a very wide variety of chemicals are available. Proteins, polysaccharides, lipids, or any combination of these substances can be used to create edible coatings and films, but the nature of these constituent materials has a significant impact on how well the coatings and films work [69]. Generally, lipids are a possible coating or film-forming substance in this context since the mechanical and barrier properties of edible films are strongly related to the polarity of film components. Lipids are defined as tiny, hydrophobic, naturally occurring compounds. Examples include fats, waxes, sterols, fat-soluble vitamins, and others. Having look at lipids, hydrophobic compounds (lipids) are typically used as a barrier against the transmission of water vapor due to their polar property. Lipid compounds often exhibit mass transfer resistance to vapor and gas transport due to both their hydrophobic nature and structural makeup. To increase the hydrophobicity of edible films, a variety of lipid compounds can be utilized. The waxes of natural origin, vegetable oils, aceto-glycerides, and fatty acids are among the hydrophobic substances that exhibit good potential [70]. Generally, hydrocolloid films are frequently enhanced with lipid components, such as fatty acids and natural waxes, to improve their water barrier qualities [71, 72].

Triglycerides, the main component of fats and oils, are derived from plants and animals, respectively. Although this combination differs physically because fats are solids

and oils are liquids, it is chemically comparable [73]. In 2016, Rodrigues et al. created a palm fruit oil film with preferred water resistance and water vapor barrier for food packaging [74]. In order to improve the quality of food, Vargas et al. (2011) utilized sunflower oil in edible coatings and on pig meat hamburgers. This was done because it was crucial to oxygenate meat and control water vapor in order to avoid an unfavorable reaction [75]. Rice bran oil was tested by Hassani et al. (2012) to increase the shelf life of kiwi fruit. Fruits were mostly preserved based on flavor, color, and firmness [76]. Another level source for the creation of edible films is essential oils. By lowering lipid oxidation, essential oils obtained from diverse plants can increase the shelf-life of food. The water vapor permeability of the films is decreased by adding essential oils [77, 78]. The growth of yeast, bacteria, and mold is inhibited by the use of anise oil, clove oil, and cinnamon oil. The shelf life of dried fish may be extended from 3 to 21 days by adding anise oil (4–6%) to an edible film. This prevents the formation of yeast, bacteria, and mold [79]. One of the main drawbacks is that strong aromas found in essential oils may alter the organoleptic characteristics of food items. Additionally, some essential oils have the propensity to cause allergic reaction issues. As a result, the concentration of essential oils affects their toxicity and organoleptic characteristics [80]. In talk, Aloe veras also considered an appreciable candidate in the food industry being edible material. *A. vera* gel's primary applications are in the sectors of cosmetics and medicine because of its anti-inflammatory, antiviral, and anticancer properties. It has, however, recently found use as edible films for ice cream, drinks, and other liquids [81–83].

3.4 Synthetic and composite edible polymers

Diverse edible polymers that combine polysaccharides, proteins, and/or lipids may exist in nature. Synthetic and composite films are prepared by the use of multiple components. The purpose of using numerous components is to gain benefits from their synergistic interactions. This strategy enables one to make use of the unique functional traits of each type of film former. Proteins and carbohydrates, proteins and lipids, carbohydrates and lipids, synthetic polymers, and natural polymers can all be combined to make films [7]. These heterogeneous films were applied in a variety of ways, including consecutive layers, a solution in a common solvent, an emulsion, suspension, or dispersion of the non-miscible ingredients. The barrier qualities of the produced films are influenced by the application technique. Kamper and Fennema have developed emulsion films made of methylcellulose and fatty acids in order to enhance the vapor barrier property of cellulose film [84]. Composite edible polymer films exhibit good barrier qualities because a hydrophilic layer and a hydrophobic layer, which includes lipids, bind together [85]. Composite edible films have been categorized as binary or ternary based on the quantity of biopolymers, as illustrated in **Figure 3**. A binary edible film made of locust bean gum (LBG) and carrageenan is a famous example [87]. Many combinations of carbohydrate-carbohydrate, carbohydrate-protein, and protein-protein are feasible in such systems [88–90]. There is a large body of literature on composite films and coatings made from the combination of two hydrocolloids, but the combination of three hydrocolloids for the creation of edible films or coatings is uncommon. A wide range of polysaccharide-based materials, including tamarind starches, have lately been employed in the production of edible films (Chandra mohan et al. 2016). PVA/Syzygium cumini leaves extract (PSN) and PVA/chitosan/S. cumini leaves extract blend films were prepared as potential candidates in packaging material to extend the shelf life of foodstuffs [65]. In order to increase the mechanical, thermal, and antibacterial characteristics of chitosan

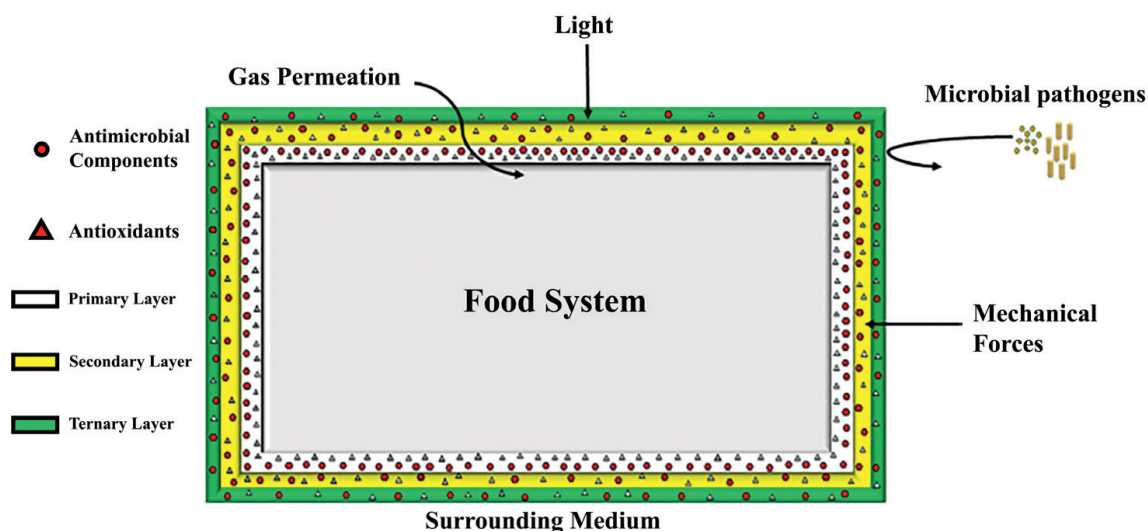


Figure 3. Barrier characteristics of composite edible films and coatings are shown schematically [86].

films, betel leaf extract (BE) was included into chitosan and chitosan/vanillin (CH/Vn) mix films [91]. The researchers confirmed that the plant-extract-doped polymer material may be used as a new antibacterial agent in food packaging. Looking into different series, such as chitosan and its nanoparticles, cellulose derivatives, including methyl cellulose and hydroxyl propyl methyl cellulose, pullulan, and natural gums, were prepared and studied as edible packaging material [92–94]. Many natural gums have been extracted from different sources, such as gum ghatti, locust bean gum, and sage seed gum [87, 95, 96]. Furthermore, proteins and polysaccharides have found extensive use in the creation of edible films and coatings. Some of the model proteins include whey protein, sodium caseinate, soya protein isolates, and collagen [97–99].

Suppakul et al. has prepared the soy protein and corn zein bilayer edible film for coating olive oil condiments. Study reported that incorporation of corn zein enhanced the tensile strength, moisture barrier properties, reduced the elongation at break and oxygen barrier properties [89]. Author Gu and Wang et al. has prepared the zein/gliadin binary film. Study reported that improved flexibility elongation at break, decreased brittleness and gliadin has significant impact on moisture content and solubility [100]. In another work, Song et al. created binary films out of scarcely bran protein and gelatin [101]. Authors concluded prepared films exhibited excellent film forming properties and composite film was complexed with grapefruit seed extract to enhance the antibacterial and antioxidant properties. The result of the study showed, when compared to the control preparation, the count of escherichia coli O157:H7 and listeria monocytogenes was dramatically reduced (without grapefruit seed extract). Similarly, salicylic acid and acetyl salicylic acid were utilized as fillers in the zein films, and their structure and mechanical characteristics were investigated [102]. Thakur et al. has formulated the bilayer film using starch combined with ι-carrageenan. Steric acid and glycerol were used as plasticizers [90]. Furthermore, Antoniou et al. has prepared binary film using chitosan nanoparticles and tara gum and characterized for thermomechanical, antimicrobial and barrier properties [103]. Authors confirmed that complexation process improved the tensile strength and elongation at break. In addition, Mei et al. has formulated the water chestnut starch and chitosan based bi-layered films [104]. Author concluded that addition of fruit extract has influence on the pH and moisture content of the film and demonstrated better mechanical properties.

Martins et al. has fabricated the Locust bean gum combined with κ -carrageenan edible films. The study revealed that the two biopolymers had a high synergy [87].

In another research work, edible films made of chitosan and fish gelatin were irradiated with an electron beam. Quercetin was trapped in the composite film due to a decreased release profile caused by irradiation [105]. The study of gelatin/chitosan composite edible films filled with antimicrobial extract (ethanolic extracts of cinnamon, rosemary, guarana and boldo-do-chile) shown antimicrobial and antioxidant properties [106]. A number of research have concentrated on creating ternary blend films. Mention few, Jia et al. has ternary edible films using Konjac glucomannan, chitosan and soy protein isolate using glycerol as the plasticizer [99]. Wang et al. has studied the whey protein isolate, gelatin and alginate ternary edible films and demonstrated the mechanical properties and barrier properties, such as water vapor permeability and oxygen permeability [107]. A ternary edible film made of konjac glucomannan, chitosan, and nisin was created, and its physical, mechanical, barrier, optical, structural, and antibacterial characteristics were investigated [108]. In the study, it was observed that ternary blend films exhibited high tensile strength, optimum transparency, and strong antimicrobial efficacy against *S. aureus*, *L. monocytogenes*, and *B. cereus*. Wang and Rhim formulated the ternary blend films from agar, alginate, and collagen. Also, blended films were successfully functionalized with silver nanoparticles and grapefruit seed extract as antimicrobial agents [58]. Polycaprolactone, methylcellulose, and polycaprolactone were combined with several antimicrobial substances, including organic acids, rosmarinic acid, an Asian essential oil blend, and an Italian essential oil combo, to create quadruple edible films. The prepared antimicrobial films could significantly resist the growth of both *S. aureus* and *E. coli* [109].

4. Functionality and composition

The majority of foods are recognized to be vulnerable to mechanical harm, physiological degradation, water loss, and rot when in storage. As a result of water loss, plants become less turgid, which accelerates the loss of nutrients and organoleptic qualities and is a key factor in degradation. Spoilage might be reduced by using edible coatings and cold storage [110]. Edible films are often used to carry active compounds, such as antioxidants, tastes, fortified nutrients, colorants, antibacterial agents, or spices, while also acting as a barrier against gases or vapor. Controlling mass transfers, providing mechanical protection, and enhancing sensory perception are the three most crucial functions of an edible film or coating. Controlling mass transfers includes keeping food from drying out, managing gas microenvironments around food, and limiting component and additive migration in food systems. Edible films have two main functions: to maintain the food's mechanical integrity or handling features and to act as a selective barrier to different gases, moisture, aromas, and lipids. Edible films and coatings can improve the look of coated food and govern adhesion, cohesion, and durability in addition to their barrier capabilities. Edible films act as a conduit for interactions between the environment, the product, and the packaging. Typically, these interactions involve a range of physical, chemical, and biological activities that change the natural environment in which the food is packed, improving the product's sustainability, safety, quality, and shelf life [111]. Perhaps, by modifying and controlling the internal environment of individual items, edible coatings on fresh foods can offer an alternative to modified atmosphere storage by decreasing quality changes and quantity losses. Even while oxygen entry may lower food quality due to oxidation of the fragrance components in

the food, altering internal atmosphere by the application of edible coatings might exacerbate diseases linked to excessive carbon dioxide or low oxygen concentration [112]. For fresh items, edible film with higher water vapor permeability is also preferred, yet exceptionally high-water vapor permeability is also not preferred since it may cause fruit to lose too much moisture during storage. To maintain the integrity of the package throughout distribution, an edible film must have sufficient mechanical strength. Acceptance of finished items is largely determined by the sensory qualities of an edible coating or film. In conclusion, the most beneficial characteristic of edible films and coatings are their edibility and inherent biodegradability [113, 114].

4.1 Physical and mechanical protection

In general, edible films and coatings shield packed or coated foods from physical harm brought on by mechanical forces including pressure, vibration, and collision. The tensile strength of edible films should typically be lower than that of conventional plastic films, however, their elongation at break varies greatly. The majority of edible and coated films are extremely moisture-sensitive [115]. However, their physical strength decreases at greater relative humidity levels because absorbed moisture works as a plasticizer. Consider the importance of temperature in influencing the physical and mechanical qualities [116–118]. When temperatures rise over the glass transition point, materials' physical strength is drastically reduced.

4.2 Functions of migration, permeation, and barriers

Mass transfer events, such as moisture absorption, oil absorption, oxygen invasion, taste loss, unwanted odor absorption, and migration of packing materials into food in general deteriorate the quality of foodstuffs [119, 120]. Deterioration mechanism involves penetration of oxygen into foods, which causes the oxidation of food ingredients; inks, solvents, and monomeric additives in packaging materials might migrate into foods. Edible films and coatings prevent the migration phenomenon and quality deterioration [114, 116]. It is best to use stand-alone edible films to measure the transmission rates of certain migrants in order to define the barrier qualities of edible films and coatings. The majority of study has focused on the oil resistance, taste permeability, oxygen permeability, carbon dioxide permeability, and water vapor permeability of edible films.

When it comes to handling convenience, edible films and coatings provide a number of advantages. The reinforced surface strength of delicate items facilitates handling easier. Fruits and vegetables with coatings are far more resistant to bruising and tissue damage brought on by impact and vibration. Edible films and coatings serve a number of extremely important purposes, including quality maintenance and improvement [121]. They may prevent the microbiological degradation of food goods as well as surface dehydration, moisture absorption, ingredient oxidation, fragrance loss, frying oil absorption, and ingredient oxidation. In view of physical and chemical quality, edible films and coatings improve visual quality, surface smoothness, taste conveyance, edible color printing, and other marketing-related quality criteria [121].

4.3 Extension of shelf life and improvement of safety

Extension of shelf life and increased safety are closely connected to the improvement and maintenance of quality. Food items with higher protective functions have

longer shelf lives and are less likely to become contaminated by foreign objects [120–123]. Due to the recent significant rise in the market for fresh produce and minimally processed goods, it is necessary to keep these items safe and increase their shelf life [124, 125]. Improved systematic methods are required to preserve safety and shelf life due to the enormous size of modern food manufacturing, distribution networks, food service franchises, and fast food restaurants.

4.4 Transporters for active ingredients and controlled release

For food components, medicines, nutraceuticals, and agrochemicals, edible films and coatings can be used in the form of hard capsules, soft gel capsules, microcapsules, soluble strips, flexible pouches, coatings on hard particles, among other forms [120, 126]. Many food-grade preservatives and natural antimicrobials have been combined into edible film and coating materials. They act as successful examples of how to efficiently inactivate spoilage or pathogenic bacteria on the surface of susceptible food items [127, 128]. To prevent the autooxidation of high-fat food items, natural antioxidants have also been integrated into edible film and coating materials [129]. The capacity for regulated release is the most crucial factor to consider when evaluating the efficacy of various applications [123]. One needs to concentrate on this because various release rates, such as instantaneous release, gradual release, a particular release rate, or non-migration of active chemicals, are necessary depending on the application. To create controlled-release systems, a variety of different active ingredients can be added to film-forming polymers. Antimicrobials, antioxidants, bioactive nutraceuticals, medicines, flavors, inks, fertilizers, insecticides, insect repellents, and medical/biotechnology diagnostic agents are good examples of active chemicals needing certain migration rates. To inactivate contaminated spoilage or pathogenic bacteria, several natural phenolic compounds have been added to edible coating materials and applied to microbiologically vulnerable foods [130–134].

5. Fabrication of edible films

Understanding the chemical makeup and structural details of additives, biopolymers, and other materials that create films is crucial for configuring them for particular uses [122, 135]. It is crucial to use a solvent that is both water and ethanol soluble when wet casting or combining active agents. There two types of film-making techniques are dry and wet [116]. In dry method of making edible films does not require liquid solvents, such as water or alcohol. Dry techniques include molten casting, extrusion, and heat pressing. Generally, heat is provided to the film-forming materials during the dry process to raise the temperature over the melting point of the film forming ingredients, causing them to flow. During film preparation, it is important to note down the impact of plasticizers and other additives on the thermoplasticity of film-forming materials must be determined. Plasticizers lower the glass transition temperature.

The wet technique disperses film-forming ingredients in solvents before drying to remove the solvent and produce a film structure. One of the most significant components of the wet process is solvent selection. Only water, ethanol, and their combinations are suitable as solvents since the film-forming solution needs to be eatable and biodegradable [136]. To create film-forming solutions, all the components of film-forming materials should be dissolved or uniformly distributed in the solvents. By using a sprayer, spreader, or dipping roller, the film-forming solution should be

Edible matrix	Industry waste	Edible film	Reference
Polysaccharides	Sugarcane bagasse	Starch (4%), glycerol (20% dry weight), water, and appropriate amount of cellulose nanocrystals obtained from sugarcane bagasse (3% dry weight)	[18]
	<i>P. densiflora</i> leaves	Hemicellulose fractions of <i>P. densiflora</i> leaves with 1% w/w polysaccharide) lecithin	[19]
	Cotton linter pulp	Crystalline cellulose nanofibrils from cotton linter pulp to reinforce sodium carboxymethyl cellulose films (2% w/v) and 0.9 g of glycerol (30 wt %) to 150 mL of distilled water	[20]
	Soybean chaff	Composite alginate films obtained from alginate–carbohydrate solutions containing 5 wt % alginate and 0.25 wt % cellulose extracted from soybean chaff	[21]
	Apple, carrot, and hibiscus	Apple, carrot, and hibiscus-based pectin edible films	[137]
	Lime bagasse and lime pomace pectic extracts	Lime bagasse pectic extract and lime pomace pectic extract at 0.70, 0.85, and 1.00% pectin equivalents with Mexican lime EO and 0.70 wt % glycerol plasticizer	[138]
	Pectin from citrus	Microparticles and films containing sunflower oil produced by ionic gelation with a 1:1 alginate–pectin mixture and electrostatically coated with whey and egg white proteins	[139]
	<i>M. stellatus</i> seaweeds	Hybrid carrageenan extracted from <i>M. stellatus</i> seaweeds	[140]
	<i>Pyropia columbina</i> red algae	Carrageenan/porphyran-based films obtained from a <i>P. columbina</i> aqueous fraction formed by casting from aqueous dispersions with different levels of glycerol	[141]
	<i>M. stellatus</i> seaweed	Edible active films from different <i>M. stellatus</i> crude aqueous extracts	[142]
	<i>Porphyra columbina</i> seaweed	Antioxidant phycobiliprotein/phyco colloid-based films obtained from mixtures of two aqueous fractions extracted from <i>P. columbina</i> red seaweed	[143]
	Brown seaweeds <i>Laminaria digitata</i> and <i>Ascophyllum nodosum</i>	Film-forming carbohydrate-rich extracts from the brown seaweeds <i>L. digitata</i> and <i>A. nodosum</i> obtained with Na ₂ CO ₃ or NaOH at different temperatures and with different acid pretreatments (H ₂ SO ₄ and HCl)	[144]
	Chitosan and protein concentrate from shrimp waste	Chitosan solution (2% w/w) dissolved in a 0.15 M lactic acid solution (pH 3.2) and sonicated	[145]
	Chitosan and potato and cassava starches	Starch and chitosan films obtained by the variation of the starch source (potato and cassava starches), starch concentration (0.5 and 1.0 wt %), and type of plasticizer (glucose and glycerol)	[146]
	Marine industry byproducts: chitosan and fish gelatin	Chitosan and fish gelatin (1:1 w/w), entrapping natural antioxidants [ferulic acid, quercetin, and tyrosol (~50 mg/g)], used to prepare edible active films by casting	[147, 148]
	Chitosan and zein	Composite edible films fabricated with zein and chitosan and supplemented with phenolic compounds (ferulic acid or gallic acid) and dicarboxylic acids (adipic acid or succinic acid)	[149]
	Cashew tree gum	Starch-cashew tree gum nanocomposite film; sage seed gum edible films with two different plasticizers (glycerol and sorbitol: 20, 40, 60, 80, and 100% w/w)	[150]
	Locust bean gum	0.4 and 0.6% w/v κ-carrageenan and locust bean gum suspended in distilled water under agitation for 1 h at 25°C with 0.3% w/v glycerol (87% v/v) in solution and homogenized at 80°C for 30 min	[151]
	Basil seed gum	Basil seed gum and different plasticizer concentrations added to deionized water and heated to 80°C under mild stirring	[152, 153]
	Brea gum	Brea gum (10% w/v), glycerol (25% w/w Brea gum), water, and montmorillonite (5% w/w Brea gum)	[154, 155]

Table 2.
Several edible films prepared using polysaccharide as edible matrix and industrial waste.

applied to flat surfaces. Once cured, the solvent should be removed to create a film structure. The development of uniform edible film and coating systems including active additives depends heavily on the components' compatibility with the solvent. To create film-forming solutions, all constituents, including active additives, biopolymers, and plasticizers, should be uniformly dissolved in the solvent. The coating procedure is also impacted by the film-forming solution's viscosity. A reduced viscosity speeds up the film-forming solution's separation from the flat surface, which results in an uneven coating on the surface and the coating solution trickling down to the floor. To decrease this coating phase separation, higher viscosity of the film-forming fluid is preferred, unless doing so results in an unacceptably thick coating thickness. The likelihood of a film layer developing on the flat surface during the high-speed coating process increases if the film-forming solution has lower surface tension and a greater viscosity. However, coated films' lower surface energies after drying make it more difficult to remove the film off flat surfaces. **Table 2** summarizes the different edible films prepared using polysaccharide as edible matrix and industrial waste.

System that is commercially viable includes new processing technologies, such as extrusion, roll orientation, conveyor drying, bath coating, pan coating, or other procedures, which would be needed to produce edible films and coatings. These new manufacturing technologies should be economically viable and compatible with the methods now used to produce packaging films and food coatings. Therefore, composition of film-forming materials should be carefully tuned, and the film-forming processes must be updated correspondingly, to fulfill the feasibility of new production systems [1].

6. Characterization and performance analysis

The appropriate use of edible packaging films largely depends on their mechanical and barrier properties. Therefore, it is critical to establish precise approaches for assessing film performances, particularly for the measurement of permeability values that can be effectively applied to forecast the self-life of products. The instruments employed to determine permeability are standardized ones and available for water vapor and permanent gas transfers. They were developed for use with synthetic and plastic packaging films. The rate of water vapor transmission per unit area of flat material with a unit thickness and per unit vapor pressure differential between two particular surfaces, under predetermined temperature and humidity conditions, is known as water vapor permeability (WVP). Based on infrared sensors, such as the Permatran-W series offered by Mocon, or WVP tester L80–4000 series of Dr. Lissy which works on the principle of coulombic or spectrophotometer method several methodologies have been refined by Holland and Santangelo [156]. In contrast to hydrophilic polymers, these approaches are particularly suited for high-barrier efficiency polymers, such as plastics or wax-based edible films [157]. The “cup method,” which is based on the gravimetric methodology, is the approach most frequently utilized by those who work on edible packaging.

For the purposes of applying edible coatings on fruits and vegetables, it was frequently investigated how permeable they were to gases, especially oxygen and carbon dioxide. The ASTM D1434 and ISO 2556 standards' manometric and volumetric methodologies were not used for edible films [158, 159]. In this regard, Oxtran device was the best one that could be used to measure gas permeability through edible films. As a result, plastic research on the gas permeability of edible packaging

was conducted using the gas chromatographic method created by Karel et al. and Lieberman et al. for collagen films [160, 161]. A gas chromatographic technique has recently been improved by Debeaufort and Voilley to quantify permanent gases, water, and organic vapor [162]. If the mechanical qualities of an edible film or coating do not allow for the maintenance of the film togetherness during usage, packing, and transport procedures, even one with excellent barrier properties may not be effective. Therefore, it is necessary to ascertain the mechanical strength and injury of edible films. To analyze the tensile strength, young's modulus, elongation at break, and elasticity of edible films, instruments, such as a universal testing machine, dynamic mechanical thermal analyzer, and texturometer, are frequently utilized [163]. Numerous other aspects of films are frequently researched, particularly in order to comprehend their mechanical and barrier properties, such as thickness, degradability, solubility, opacity, color, antimicrobial activity, and thermal stability.

7. Rheology of edible films

Ideally, the functional characteristics of a packaging film, more especially the physical and rheological characteristics of a film-forming solution, can be used to verify the film's performance (FFS). In fact, rheological characteristics are crucial to the creation of high-quality composite films. They must be taken into account while enhancing the design process since they have an impact on the spreadability, thickness, uniformity, and functioning of FFS [164]. It is well-known fact that physical parameters of film plays are crucial to investigate the properties, such as tensile strength, Young's modulus, and elongation at break. In addition, the physical characteristics of films were also examined, such as their shape, morphology (heterogeneous and homogeneous), solubility as well as their transparency, and light transmission. The rheological characteristics associated with the film-forming solutions play a crucial role in defining properties, such as thickness, dispersion, and uniformity of liquid coating layer, applied to the edible film by dipping brushing or spraying. Also, with respect to film formation, a moderate viscosity is the required flow property for the film-forming solution since high or low viscosities would result in uneven film formation [165]. For coating applications, some writers have advised a viscosity lower than 700 mPas; however, the proper viscosity for other film solution treatment circumstances, such as mixing, pumping, and transfer to the casting line, as well as spreading the solution smoothly, is around 1000–10,000 mPas [166, 167]. The behavior of the flow of film solutions has an impact on the mechanical properties and the optimization of the designing process during application. Additionally, it is claimed that rheological parameters can be used to assess how polysaccharide solution systems' structure–function interaction [168]. Therefore, modification and alteration in the molecular structure, it is required to analyze the rheological characteristics of the edible film solutions in order to provide a comprehensive understanding of the physical characteristics of edible films.

Ideally speaking on influence of concentration degree of deacetylation (DD), for example, an increase in the concentration of glycerol has a significant influence on apparent viscosity (AV), consistency coefficient (CC), and flow behavior index values of deacetylation samples. In one study addition of 5% glycerol has shown descending order of AV and CC of prepared films. At a subsequent addition of glycerol (10%), these values did, however, continue to decline for only 100DD samples. The samples' pseudoplastic behavior was shown by the n values, which ranged from 0.70 to 0.77

[169]. Principally, it was connected to the network's polysaccharide macromolecules with a lot of hydroxyl groups being destroyed by shearing [170]. In terms of pseudo-plastic flow behavior, AV, and CC values, only the 100DD-10G (n = 0.77) sample was less favorable. As a result, this solution disperses and flows more readily, reflecting the fact that glycerol has disrupted the intermolecular link among the glucomannan polysaccharides. Therefore, glycerol's inhibition impact was more pronounced for 100DD. Glycerol increase may be offered at a lower DD, preserving the properties of the existing hydrogen bonds while creating new ones.

In our previous work, we tried to figure out influence of *Syzygium cumini* (*S. cumini*) leaves extract, morphological, thermal, and mechanical as well as on anti-microbial activity of the PVA and PVA/chitosan blend films for packaging applications [171]. The findings showed that the *S. cumini* leaves extract in PVA and PVA/chitosan films had a significant physical interaction at lower concentrations, which contributed to the films' smooth uniform morphology, increased degree of crystallinity, lower degradation temperature, and improved mechanical properties. **Table 3** depicts the mechanical properties of PVA and PVA/chitosan-doped blend films. As it is observed that at a lower concentration of *S. cumini* leaves extract, tensile strength increased, elongation at break and Young's modulus decreased. **Figure 4** depicts the SEM micrographs of pure PVA, chitosan, PSN-1, PSN-4, PCS-1, PCS-3, PCSHN-1, PCHSN-3, PCHS-1, and PCHS-4 blend films [171].

Figure 5 it is depicted that, binary PVA/*S. cumini* leaves extract showed smooth homogeneous morphology, whereas high concentration of *S. cumini* leaves extract

Sl. No	Sample Name	Tensile strength (Ts)	Young's modulus (Ym)	Elongation at break (%Eb)
01	Chitosan	40.37 ± 2	1603.69	3.90
02	PVA	21.70±	24.48	394.32
03	PSn-1	24.95±	27.58	317.12
04	PSn-2	23.24	18.85	342.55
05	PSn-3	12.17	24.98	242.46
06	PSn-4	20.00	22.95	296.06
07	PchSn-1	30.81	23.18	213.10
08	PchSn-2	14.74	23.16	150.72
09	PchSn-3	19.11	19.11	135.05
10	PchSn-4	21.76	21.76	153.72
11	PCS3	62.96	18.42	11.67
12	PCS4	48.08	61.26	117.82
13	PCS5	18.83	22.59	138.97
14	PChs-1	36.14	81.781	65.43
15	PChs-2	26.41	63.66	59.11
16	PChs-3	30.26	76.25	60.51
17	PChs-4	32.32	114.30	59.10

Table 3.
 Mechanical properties of PVA, chitosan, and blend films.

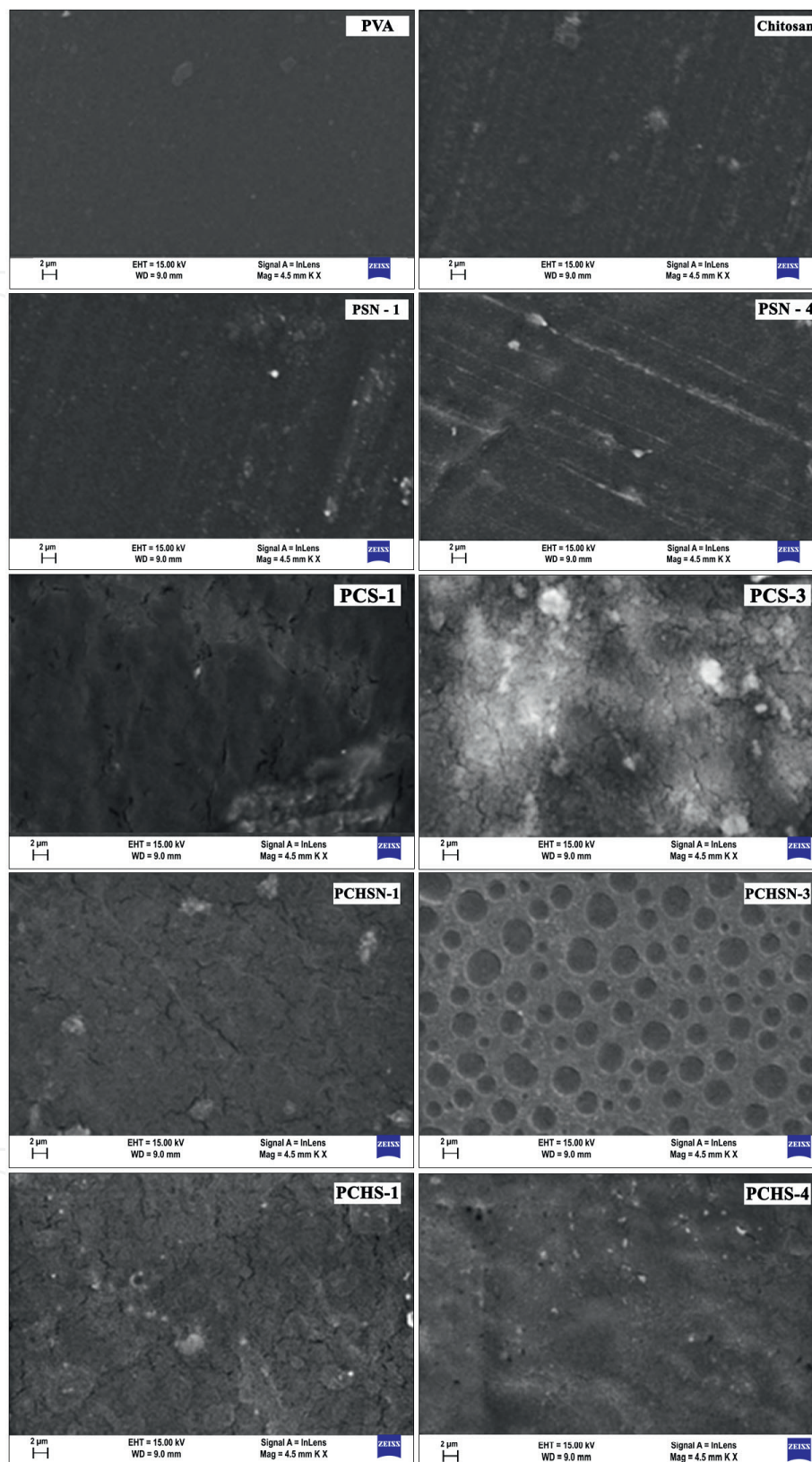


Figure 4. SEM micrographs of pure PVA, chitosan, PSN-1, PSN-4, PCS-1, PCS-3, PCSHN-1, PCHSN-3, PCHS-1, and PCHS-4 blend films [171].

(PSN-4) showed low compatibility exhibiting strand-like appearance, indicating phase separation. Similarly, in another work, we tried to analyze influence of Betel leaves extract on chitosan/vanillin films [91].

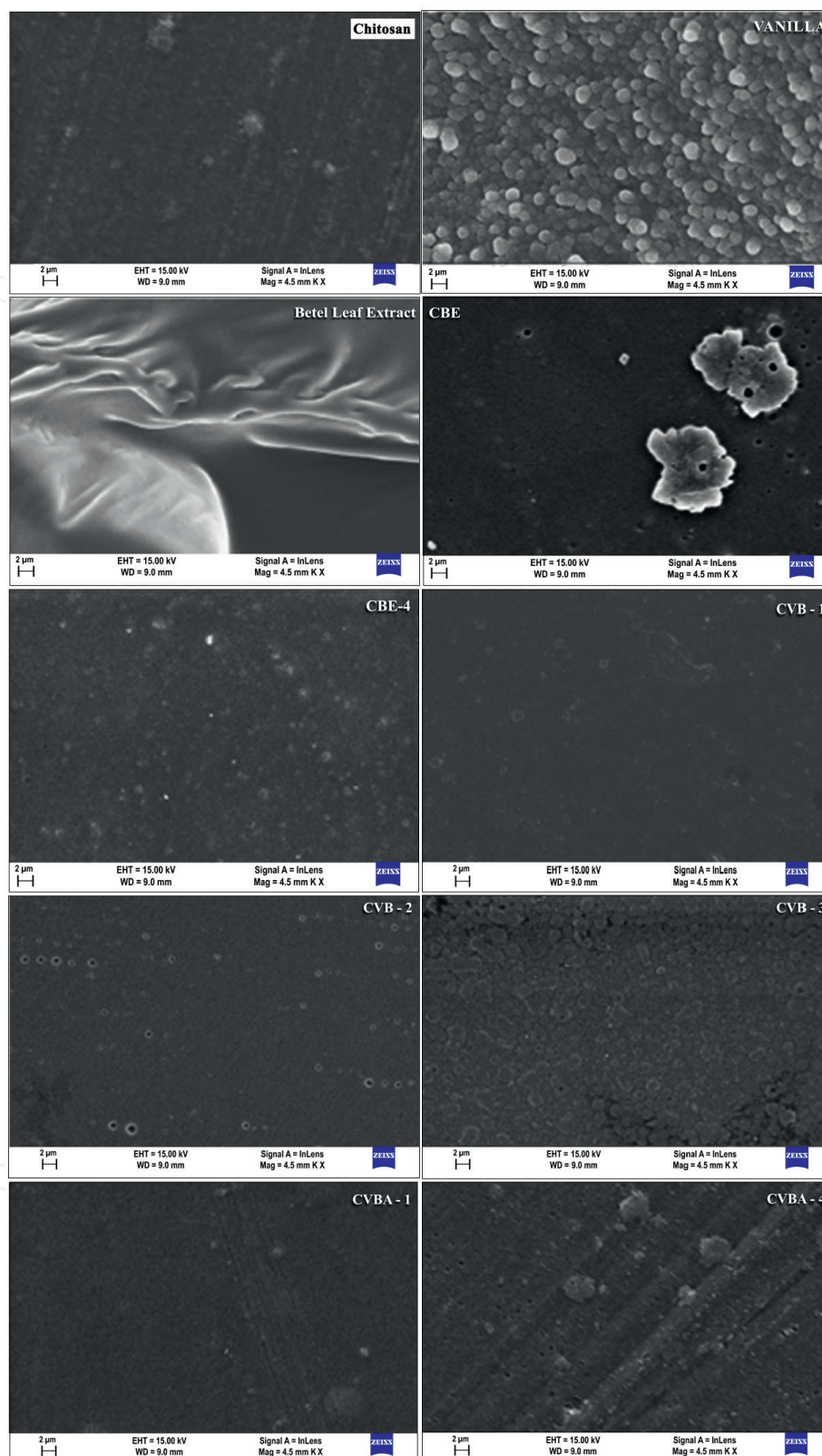


Figure 5. Scanning electron microscopy micrographs of pure chitosan, vanillin, betel leaf extract, CH/BE (CBE) and CH/Vn/BE (CVB, CVBA) blend films [91].

Figure 6 presents the SEM micrographs of different Betel leaf extract (BE) doped chitosan blend films. At a lower concentration of BE, smooth homogeneous morphology was observed (CBE-1), later at a higher concentration of BE immiscibility was noticed (CBE-4). In case of ternary blend films Chitosan/vanillin/BE, showed good

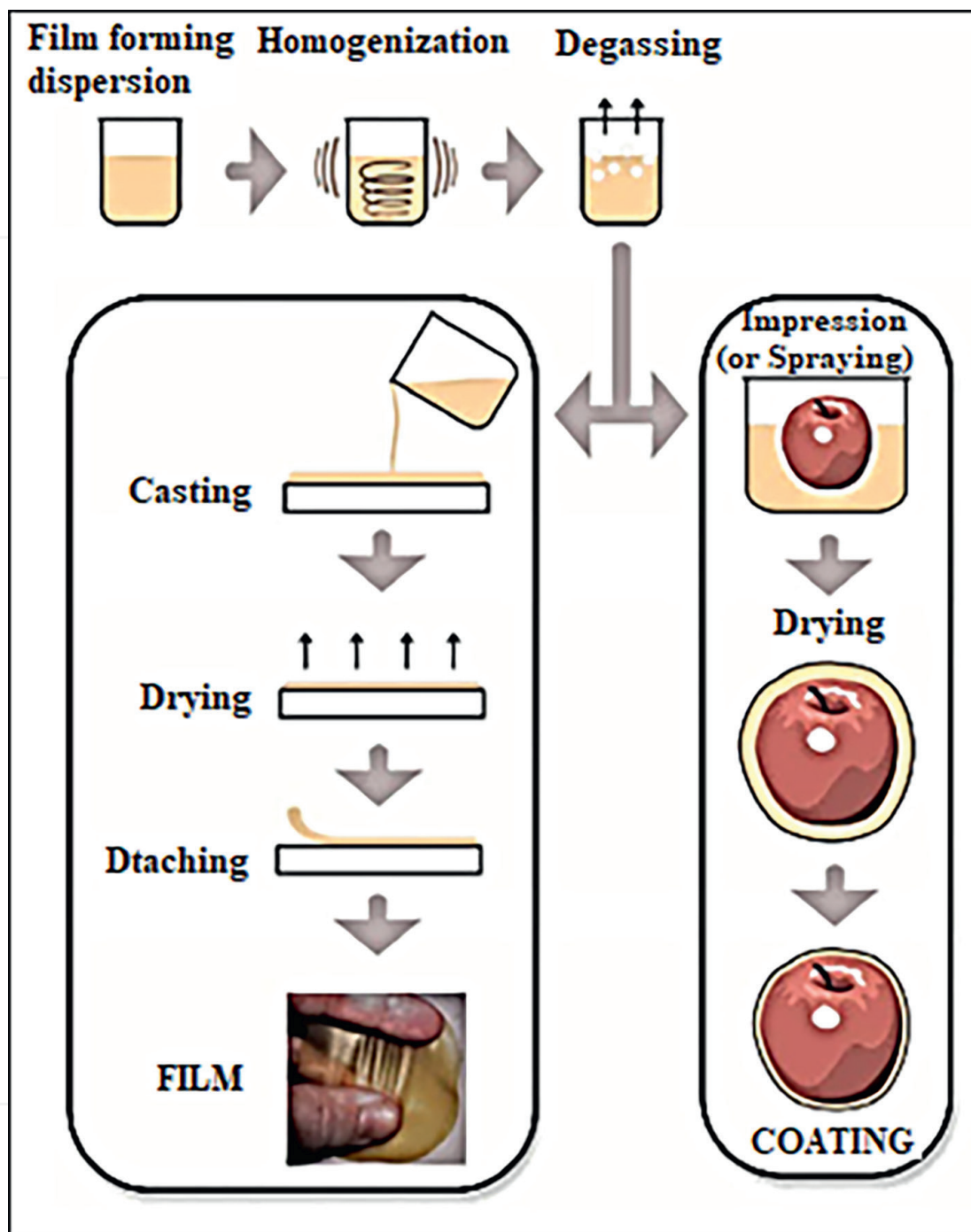


Figure 6.
Edible films and coatings: schematic presentation [172].

miscibility and smooth homogeneous morphology (CVB-1 and CVBA-1) due to compatibility of BE at molecular level as chitosan is recovered by the vanillin network implying the appreciable adhesion and compatibility [91]. Similarly, X-ray diffractogram of binary chitosan/BE films showed a significant change in 2θ value, indicating the decrease in degree of crystallinity (51.59, 70.89, and 31.94%) with an increase in the filler BE, attributed to the dispersion of BE lead to the weak interaction in the chitosan matrix. The diffraction model of ternary CH/Vn/BE blend films showed diffraction peaks at 18.50, 20.39, 28.50, 35.09 and 42.19° for CVB-1; 22.2, 31.09, 34.30 and 44.90° for CVB-2; and 7.06, 20.59, 22.79, 28.49 and 38.49° for CVB-3. The $2q$ value in each

formulation was significantly improved by the addition of BE, lengthening the distance between the chitosan chains. The findings from the contact angle investigation and the oxygen barrier qualities may be closely connected with this [91].

8. Concerns relating to consumers

Consumer acceptability may have a considerable impact on the potential usage of edible materials because edible films are consumable components of food products [1]. Consumer acceptability, which is influenced by organoleptic characteristics, welfare, selling, and cultural resistance to the use of new materials, is a comprehensive indicator of consumers' subjective product preferences. However, it is important to note down organoleptic characteristics, including flavor, odorless, sensory feasibility with packed foodstuffs, texture, and appearance [135]. Innovative edible film's potential for toxicity or allergenicity and microbiota changes in packaging stuffs are major safety concerns. More than consumer approval, there are several other issues that prevent edible films from being used commercially, including complexity associated with the production, huge investment to install new film manufacturing equipment, potential conflict with traditional packaging, and regulatory issues.

9. Applications

Heightened active packaging concept is a result of growing consumer demand for retaining quality and freshness of foodstuffs higher quality. A kind of packaging material that modifies the environment around the food to preserve food quality and freshness, enhance sensory qualities, or lengthen food safety and shelf life. In this regard. Edible films are considered suitable candidates for packaging as they are eco-friendly and biodegradable in nature. Generally, edible films are used to pack vegetables, fruits, meat, fish, dairy products (cheese, milk, and yogurt), and poultry products. Various examples of packaging materials include biopolymers, bioplastics, and edible films prepared from natural origin raw materials from agricultural or marine sources [78].

9.1 Edible films for meat, poultry, and seafood packaging

Generally, active edible films provide a preservative barrier to products made from meat, poultry, and seafoods. As this food is quite perishable due to high percentage of water. Edible films around the meat products protect the shrinkage loss, retain discoloration, resist microbial attack, and oxidative off-flavor. A variety of edible biopolymers are employed as coatings for meat products [173, 174]. With advantageous properties, such as biopolymer, hydrophilic, and good film-forming ability, author Kontominas MG have investigated sodium alginate-based edible films by mixing active and antimicrobial agents to enhance the shelf-life of meat product [175]. Author Takma and colleagues prepared the alginate-based edible films using black cumin oil as an antimicrobial agent to pack chicken breast meat [176]. Furthermore, Qussalah et al. have proved sodium alginate films successfully inhibit *Salmonella typhimurium* when mixed with cinnamon, savory, and oregano oil [177].

However, Seafood is most perishable food material which has a very short shelf life also contamination possibilities are more during transportation due to surrounding

environment, which leads to the spoilage of quality and loss of nutritional values and may lead to foodborne diseases. To ensure quality and shelf-life use of antimicrobial agents in the catfish gelatin which helps to control microbial attack and enhances the shelf life of shrimp by nearly about 10 days. Gelatin and whey protein-based enriched films doped with cinnamon oil and clove essential oil as an active antimicrobial agent retards the microbial attack on rainbow trout fish and active agent improves the quality of chicken breast fillet's shelf life [178, 179].

9.2 Edible films for packaging of dairy products

Every day we consume dairy products, including cheese, yogurt, and milk which are an essential part of our daily diet. Among others, specifically, cheese is rich in lipids, proteins, and vitamins. Having said that, edible films regulate and control the ripening process, inhibit mass transfer, and lengthen the shelf life. Different edible casting techniques include spraying, dipping, brushing and electrostatic brushing, and casting is used to prepare film. Film covered on the cheese will increase the shelf life, brushing is normally used for small-sized cheese packaging, and for irregular shape cheese dipping method is preferred. Similarly, uniform and thin layer coating the cheese spraying method is most preferred one. On the other hand, electrostatic spraying prevents solution wastage and gives higher efficiency. Films prepared from casting technique generally create the barrier between the cheese and surrounding environment [180]. When compared to polysaccharide films, films fabricated from whey protein sources exhibit better gas barrier characteristics. As whey protein films are transparent in nature which allow consumer to see the quality of the cheese. Speaking of other dairy products, that is, butter, which contain high fat hence more found of lipid oxidation, and shelf life get reduces. To protect corn starch edible materials prepared using ginger oil stops lipid oxidation when stored at 2 to 5°C [181].

9.3 Edible films for packaging of fruits, vegetable, nuts, and grains

Gas exchanges via respiration and transpiration occur during ripening and storage, as well as microbial growth, particularly molds and rots, are the main causes of fruit and vegetable deterioration [182]. Most commonly waxes, such as paraffin, beeswax, shellac, carnauba, and candellilla, are utilized as coating agents for all kinds of fruits [183]. Waxes and oils are very effective water barriers that can stop weight loss, whether they are used alone or in an emulsion with hydrocolloid or protein solutions. A thick wax layer coated on fruits significantly alters the CO₂ leading to anaerobic storage that causes unequal ripening up to adulteration of fruits and vegetables [184]. Consequently, in order to have better control over the ripening, several edible films were created that increase CO₂ and ethylene evaporation while decreasing oxygen penetration in the fruit. The inherent antifungal nature of the hydrocolloid employed or the incorporation of antimicrobial compounds within the film can both delay and prevent spotting. In this way, chitosan films encourage the fruit to produce the chitinase enzyme, a naturally occurring antifungal substance. Author Mazza and Qi have investigated the coatings prepared from gums, gelatin, and starch can prevent the non-enzymatic browning of peeled and blanched potatoes [185]. The bactericidal activity against *escherichia coli* (0157:H7) of apple puree-origin FFFs added with oregano, lemongrass, or cinnamon essential oils. They concluded that prepared materials have 50% bacteria killing property (0.034, >0.34, and 0.28) after incubation for 3 min at 21°C [186]. As opposed to those with carvacrol, carrot puree edible films containing cinnamadehyde have shown

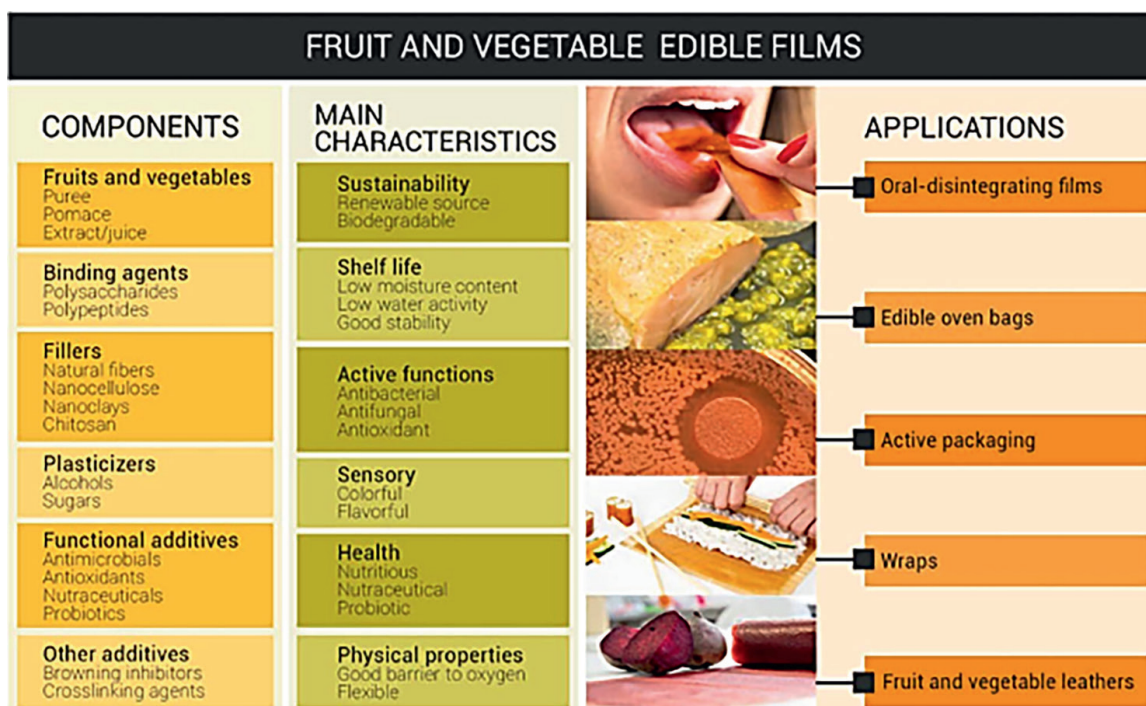


Figure 7. Components crucial to film formation, primary traits, and uses for edible films [172].

appreciable inhibitory activity of *Staphylococcus aureus* and *E. coli* [187]. Otoni and colleagues prepared papaya puree films blended with cinnamaldehyde nanoemulsions of various sizes. They reported all films to exhibit antimicrobial activity against *S. aureus*, *E. coli*, and *S. enterica* for fruits containing low preservative content [188]. Last but not least, edible films based on fruits and vegetables may also be created with unique health-promoting capabilities, such as probiotic or prebiotic films, by enhancing the market demand for sensory qualities and nutritious dietary components [189]. Therefore, applications are anticipated to be continually used in a world that is becoming more and more concerned with health-related issues. **Figure 7** summarizes the various components crucial to film formation, primary traits, and uses for edible films.

9.4 Edible films for packaging of confectionaries

Confectionary products, such as chocolates, candies, boiled sweets, toffees, and caramels, always require active packaging material which ensures protection from moisture attack, dust and dirt contaminating agents and prevents loss of sugar, fat bloom, stickiness, desiccation, and hardening. Generally, mindset is made to avoid intermixing of flavors of the various confectionary foods. In fact, milk and whey proteins, cellulose-based films, and shellac or wax lower the water and oil migrations, such as the greasy or oily feeling on fingers. Author Nelson and Fennema reported that methylcellulose films and coatings have shown lower lipid permeability which have ability to reduce fat mobility and inhibits the whitening or blooming of chocolates [190]. In comparison to the conventional confectioner's glaze, zein-ethanol bleeding employed as film-forming solution produces better results with faster drying times [126]. Author Dyhr and Sorensen have concluded that sorbitol-based coatings have ability to replace conventional sugar coatings on chewable dragees [191]. Bilayer films prepared from wax and hydrocolloid have shown improved adhesiveness which was applied on chewing gum sheets to enhance the shelf life [192].

10. The future and conclusion

The use of edible polymer films and coatings has great promise for enhancing food quality, shelf life, and safety. Continued study in the active packaging is justifiable given the potential benefits of edible polymers as carriers of antibacterial, coloring, antioxidant agents, vitamins, probiotics, and nutraceuticals. It has been realized that efficiency and active properties of edible polymers are largely influenced by the inherent properties of film-forming materials, such as biopolymers, plasticizers, and dopants. After analyzing particular functions, in both commonplace like polymers and specified applications, edible biopolymers are competitive. In an advantageous path, biopolymer can be effectively replaced by petroleum-based plastics used for packaging. Many studies have shown that active biopolymers, such as polysaccharides, lipids, and proteins, are used to prepare biodegradable polymer films. **Table 4** list out the different functions of edible films for the packaging applications.

The use of edible polymers on numerous food products is still evolving. The future enhancement of food quality and preservation during operations and storage is very bright thanks to edible polymer films and coatings. A novel innovative edible polymer is under progress, to enable the inclusion or regulated release of active chemicals using nanotechnology solutions, such as nanoencapsulation and development of multifaceted systems. As edible packaging serves intelligent packaging systems due to both active, selective, and infinite potential usage. The future trend may allow using nanoscale nutrients, different active dopants, and suitable delivery systems for biodegradable polymeric edible films in collaboration with nanotechnologies as they take a promise to improve the nutritional qualities of foods. However, nanocomposite concepts also being the motivation for novel systems in the field of edible films. Many other types of materials have been realized, and many more are on the way. However, more research is anticipated to focus on edible films and coatings' actual practical uses in the food business. Therefore, more effort is needed to manufacture desired edible polymer films and coatings for superior functionality and processing to commercial breakthrough.

	Function	Properties of edible films
Edible film, coating for food	Protection	Water and gas barrier
		Protection from light and ultraviolet
	Antimicrobial	Prevention of microbial growth
		Enhanced the food shelf-life
	Antioxidant	Prevents enzymatic browning
		More consumer acceptance
	Shelf-life	More demand in the market
		Reduces food product waste
	Esthetic	Shiny and smooth surface
		Prevents aroma loss
Sustainable	Edible and bio-based	
	Reduces plastic waste	

Table 4. Different functions of edible films for the packaging applications [193].

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Conflict of interest

The authors affirm that they have no affiliations or conflicts of interest that could have seemed to affect the research presented in this study.

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