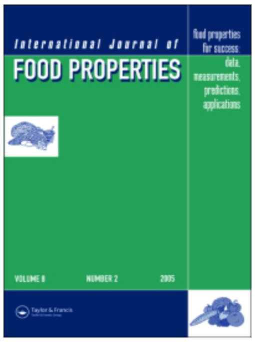

International Journal of Food Properties

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ljfp20

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To cite this article: Muhammad Armghan Khalid, Bushra Niaz, Farhan Saeed, Muhammad Afzaal, Fakhar Islam, Muzzamal Hussain, Mahwish, Hafiz Muhammad Salman Khalid, Azhari Siddeeg & Ammar Al-Farga (2022) Edible coatings for enhancing safety and quality attributes of fresh produce: A comprehensive review, International Journal of Food Properties, 25:1, 1817-1847, DOI: 10.1080/10942912.2022.2107005

To link to this article: https://doi.org/10.1080/10942912.2022.2107005

Published online: 07 Aug 2022.

INTERNATIONAL JOURNAL OF FOOD PROPERTIES
2022, VOL. 25, NO. 1, 1817–1847
https://doi.org/10.1080/10942912.2022.2107005

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Edible coatings for enhancing safety and quality attributes of fresh produce: A comprehensive review

Muhammad Armghan Khalid[a], Bushra Niaz[a], Farhan Saeed[a], Muhammad Afzaal[a], Fakhar Islam[a], Muzzamal Hussain[a], Mahwish[b], Hafiz Muhammad Salman Khalid[c], Azhari Siddeeg[d], and Ammar Al-Farga[e]

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ABSTRACT

Fresh produce is recognized as highly beneficial for human health. The substantial changes in the life-style of populations and upturn awareness about nutritional aspects of dietary patterns, fresh produce has high demand. In developing countries, postharvest losses can reach up to 50%, and improper storage can cause serious food safety and quality-related issues. To fulfill the ever increasing demand of fresh produce, more attention should be given to reduce postharvest losses in addition to increase the production. Postharvest operations are one of the promising approaches for regulating food safety and security. Recently, various technologies have emerged to preserve the fresh produce and to extend their shelf life. However, consumers demand chemical free fresh product with excellent quality and nutritional profile. In this context, edible coating of fresh produce seems to be an effective approach to mitigate produce safety and quality issues. This review explores numerous types of edible coatings with their impact on quality attributes of fresh produce, as well as the benefits and main functions of each type of coating. This valuable information could help the processors in selecting the appropriate coating material for various fresh and minimally processed foods.

ARTICLE HISTORY
Received 21 April 2022
Revised 19 July 2022
Accepted 24 July 2022

KEYWORDS
fresh produce; postharvest losses; food safety and quality; Nutrition properties; Bio-edible coating

Introduction

The global population is growing at an alarming rate and majority of this growth is concentrated in developing nations, which are already facing food safety and insecurity issues. Fulfilling the food requirements of a constantly rising worldwide population is a big challenge for mankind. World's population is expected to exceed 9.1 billion inhabitants by 2050, requiring a 70% rise in fresh produce to nourish them.[1] Horticultural commodities can assist to alleviate these problems. Horticultural crops offer a lot of potential for increasing profitability, in addition to boosting biological production and nutritional standards.[2] Accessibility and availability of food can be enhanced by elevating production, expanding distribution, and reducing postharvest losses. Reducing postharvest losses is one of the most critical components for ensuring food safety. Reduced postharvest losses, especially in poor countries, might be a long-term solution for boosting food supply, lowering dependency on natural assets, improving livelihoods, as well as eliminating hunger.[3] Many studies in literature demonstrated that 40–50% of fresh produce

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in developing nations is wasted before consumption.[4] Fresh produce is highly perishable by nature, that is why it is more susceptible to biotic (diseases, insects, parasites) and abiotic (temperature, humidity, rain, floods) challenges that cause postharvest losses. Microorganisms are a major source of postharvest losses in fresh vegetables. Skin damage, spots, and fractures occur as a result of improper handling of fresh vegetables provide optimum conditions for microbial growth. Many microorganisms enter the food and cause serious health issues, especially pathogenic organisms which can cause food-borne diseases.[5] To enhance quality and safety, fresh produce must need protection from deterioration during processing, storage, and transportation. Numerous techniques are utilized for extending the nutritional attributes and storage life of fresh produce include modified atmospheric packaging (MAP), high temperature storage, low temperature, irradiation, and chemical treatment but these techniques require proper care and sometimes lead to an unacceptable loss in nutritional value of produce.[6] In recent years, edible coatings and films have piqued the attention of scholars and the food industry to use them as preservative techniques because of their biodegradability, biocompatibility, antibacterial, and antifungal activity and it shown to be very successful in retaining food without compromising its nutritional or organoleptic aspects. Edible coatings for food preservation are not a new concept but these procedures gained immense attention in recent years due to their protective properties.[7] Edible coatings would be a good substitute for the commercial synthetic waxes that are now utilized, which are mostly made of oxidized polyethylene. Moreover, certain edible coatings may contain useful additives like antioxidants and phytonutrients that help to improve food safety and stability. Sensory properties, water solubility, and other variables all play a role in the selection of coating materials. This review focus on the edible coatings and their effects on fresh produce quality as well as the benefits and key functions of each type of coating.

Post-harvest losses

Loss of fresh produce is not a new concept; it seems to be a topic of concern from a long time in human history. In most developing countries, like Pakistan, where nutrition is usually insufficient, there is a burgeoning commitment to do the maximum possible jobs to assure food safety and security owing to reduce hunger and malnutrition. Fresh produce loss occurs from farm to market. The degree of loss that happens at the final point is strongly influenced even by pre-harvest handling.[8] Fresh produce is highly perishable owing to its active metabolism and strong physiological postharvest activity that results in quick ripening and maturity and renders their marketing a massive challenge.[9] Appropriate postharvest management is the one that allows for adequate planning of how to manage restricted resources in the future. Modified atmospheric packaging (MAP) is the most common postharvest management strategy that can be utilized to reduce postharvest losses. Figure 1 shows the percentages of rapidly spoiled food commodities.[10]

Factors affecting the safety and quality of fresh produce

Physical factors

Quality of light, intensity, relative humidity, and temperature are involved in retaining the quality and storage life of fresh produce (from harvesting to storage period). Light quality and intensity modulate the quality of fresh produce. Lightly processed and freshly cut vegetables and fruits have greater surface area and have no skin. They lose a significant quantity of weight especially at higher temperatures with a considerable vapor pressure differential. High relative humidity during storage causes microbial growth while low humidity causes loss of fruit weight. Improper temperature

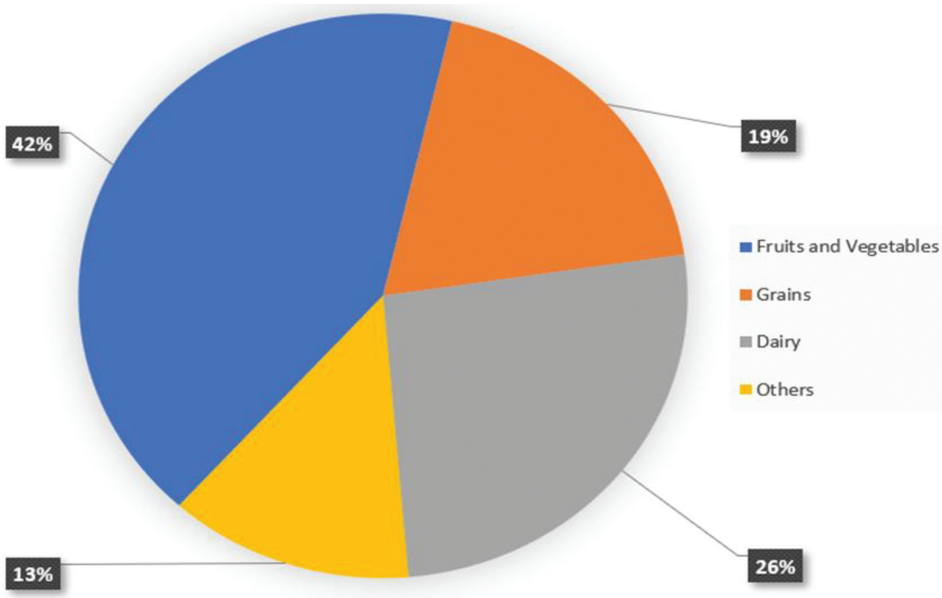

Figure 1. Percentages of rapidly spoiled food commodities (Sridhar et al., 2021).

handling led to reduction in the storage life of produce.[11] Low temperatures are mostly practiced for improving storage life but some-times, in tropical native fresh produce, it causes chilling injuries.[12]

Chemical factors

Chemical and metabolic changes take place naturally in fresh produce and result in an undesirable sensory characteristics in foodstuffs. Hydrolysis of pectin, which weakens the structure of foodstuffs, is caused by indigenous pectinases which are produced or activated during fruit ripening. Mechanical injury to fruits and veggies can activate pectinases which can result in microbial assault. As explained by Amit et al.[13] non-enzymatic browning or Millard's reaction is the most common cause of food spoilage. Amino acids and the amine group of proteins present in foodstuffs undergo this process and develop bitter flavors, dark color, and reduce nutritional accessibility of specific amino acids. Proteolysis is an irreversible post-translational alteration that includes the hydrolysis of a protein's peptide and iso-peptide bonds in a restricted and highly precise manner. Miscellaneous protease enzymes are required for the complete phenomenon to occur. Normal and pathological conditions are linked to unique proteolytic events.[14] Ethylene, a ripening hormone, even at a low quantity has a negative result on the growth, development, and storage-life of produce. The impact of ethylene is dependent on the product as well as on the temperature, exposure period, and concentration. Many products are susceptible to ethylene amount as low as 0.1 ppm if exposed for the maximum duration of time. Certain fruits, such as strawberries, produce little ethylene so they are extremely susceptible to it.[15] When greater surface area is subjected to the environment, ethylene synthesis rises resulting in softness of tissues that results in an unacceptable response by the consumer.[6]

Biological factors

Microbial deterioration is a cause of postharvest losses in fresh produce which occurs as a result of direct contact with contaminated microbes through water, soil, dust, and postharvest industrial processes. Majority of postharvest losses in vegetable and fruit crops are due to diseases caused by microbes as described by Tripathi & Dubey.[16] The major microorganisms that are responsible for fresh produce spoilage are bacteria, yeast, and mold. Many other small insects and small mammals are also responsible for food losses. Microbiological spoilage of fresh produce is linked to chemical and physical factors. For example, vegetables have high pH so their degradation is mostly caused by bacteria while fruits possess high moisture contents, nutrient contents and low pH, that's why these are more vulnerable to be attacked by fungi as reported by Tripathi & Dubey.[16]

Edible coating

This method has been used to preserve food commodities in the food sector from twelve century; and not a new process for preservation.[17] Chemical, physical, and biological improvements are blocked by edible coatings.[18] When purchasing fresh produce, consumers evaluate the quality and wholesomeness of the produce based on its presentation. The most prevalent and challenging problem for fruit industry is to maintain and control fresh quality, avoid spoilage and retard growth of pathogenic microorganisms.[19] This issue can be solved by using an edible coating. Edible coating adds another layer of protection to fresh fruits and vegetables and may have a similar effect to modify storage atmosphere and controlling inner gas composition.[20] In recent decades, edible coatings with the inclusion of different edible herbs and antimicrobial agents have been created and applied to fresh produce.[21] Edible coating is a thin layer that acts as semipermeable membrane and operates as barrier against gases, water leakage, hence, decreases the rate of respiration, enzymatic browning, and release of volatile compounds into the ambient environment.[22] They are employed directly on the produce surface by spraying, brushing, or dipping to create a modified atmosphere. Under conditions of high humidity, edible coatings should be durable and commonly regarded as safe. Edible coatings must be colorless, odorless, tasteless and have strong mechanical characteristics that can be utilized as nutraceutical, as well as act carriers of texture enhancers. To enhance the storage life of fresh produce, various materials were used to cover and wrap them and this material is consumed with foods, both with and without removal, and is known as an edible wrapping. Fresh produce with edible coatings has a gleaming appearance. The key benefit of edible coating is that it improves the storage time of fresh or refined food products while also protecting them from postharvest losses and environmental damages.[23] Figure 2 depicts the key role of edible coatings in food packaging.[24]

Espino-Díaz et al.[25] stated that edible coating is added to the outer surface of fruits and vegetables to increase shelf life and shine appearance in order to meet market demand for environment friendly and nutritious foods by improving the nutritional composition of fruits and vegetables without compromising their consistency. Among the major obstacles confronting the global preservation industry is the limited advancement of unique coatings with increased consistency and functionality for both fresh and minimally processed food. It has been documented that development activities have largely turned toward the creation of environmentally sustainable coatings/packaging derived from biodegradable polymers, which may not only minimize packaging needs but also contribute to the transfer of value-added by-products.[26]

Edible coating forming methods

Multiple methods are employed for coating formation depending upon which coating material is used. For the formation of edible coatings, some methods like solidification of melt, solvent extraction and thermal gelation have been developed.[7] Hydrocolloid films contain water soluble polymers derived from animals, plants, or microbial/biological sources. Solvent extraction produces hydrocolloid edible films with a continuous structure. The chemical and physical interactions between molecules enhance

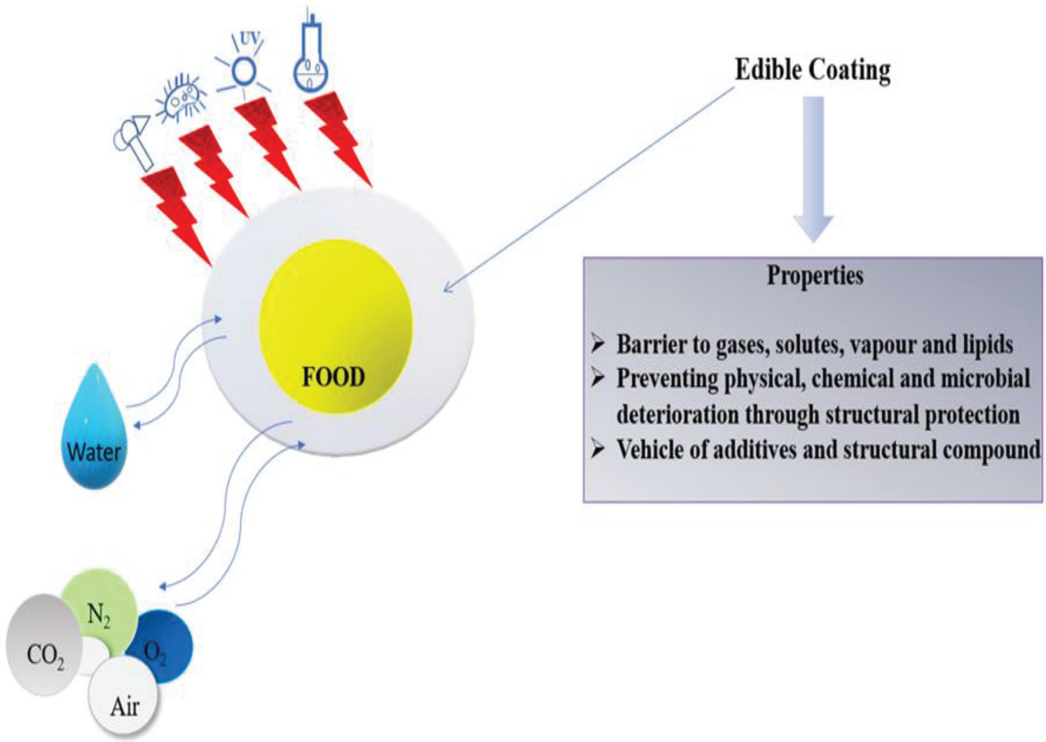

Figure 2. Key role of edible coatings in food packaging (Valdés et al., 2017).

the product's stability. Water, acetic acid and ethanol are mostly used as solvents with the addition of plasticizers, antimicrobial, and cross-linking agents. Protein films produced by heating the solution result in denaturation, precipitation, or gelation and cooled immediately to produce coagulation and further gelation. Lipid films are solidified and melted.[7]

Additives in coatings

Additives like antimicrobials, plasticizers, texture enhancers, flavor, probiotics, and anti-browning compounds have been mostly utilized in edible coatings. Incorporation of antimicrobial agent into coatings give an innovative approach to extend the storage life and enhance microbial safety.[27] The generally utilized antibacterial agents in edible coatings are potassium-sorbate, lauric acid, green tea powder, sodium benzoate, trisodium phosphate, pediocin, lactic acid, conalbumin, chitosan, lecithin, nisin, lauric acid, ethylene diamine tetra acetic acid (EDTA), thiosulfonates, imazali, sorbic acid, grape seed extract, essential oils/spices, or their ingredients, benomyl, silver, isothiocyanates, and enzymes. The enzymes glucose oxidase, lactoperoxidases, and lysozyme are utilized as antibacterial agents in coating solutions, however, their applicability is limited due to poor stability (at varying pH and temperature).[28] Antimicrobial compounds derived from plants are encouraged to promote customer acceptance. Dhital et al.[29] used natural antimicrobials curcumin and limonene and coatings were made from their liposomes and then over-coated with methyl cellulose. One set of each coating type was exposed to simulated local transportation vibration. Vibrated samples had a shorter shelf life than non-vibrated samples, indicating the need for a tough coating that can withstand road vibrations. On the 14th day of storage, limonene liposomes showed substantially lower fungal growth than the control by judging number of strawberries with visible mold. Olivas et al.[30] studied the impact of four distinct plasticizers (glycerol, polyethylene glycol, sorbitol,

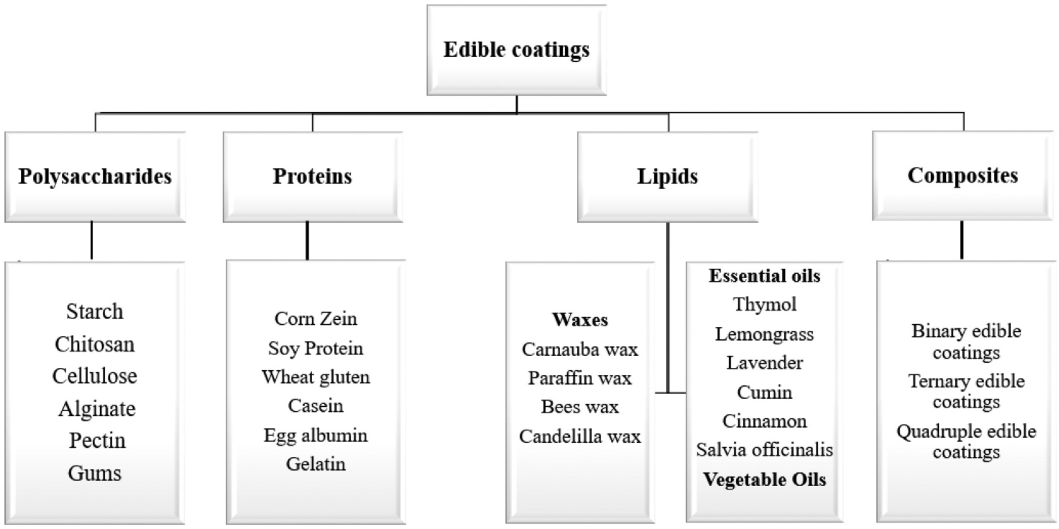

Figure 3. Types and subtypes of edible coatings.

and glycerol) on water vapor permeability, and mechanical characteristics of alginate coating. Inclusion of plasticizers changed the mechanical characteristics of alginate coverings, lowering tensile strength (TS), with the impact becoming more evident as the relative humidity (RH) increased.

Types of edible coating

Edible coatings are chiefly classified into three main groups. Polysaccharides based coatings (starch, chitosan, cellulose, alginate, pectin, gums etc.), protein-based coatings (zein, whey protein, wheat gluten, casein, soy protein, egg albumin, gelatin, etc.), lipid-based coatings (waxes, fatty acids etc.) and composite coatings are formed by combining more than one material or substance.[31] Figure 3 depicted the types and subtypes of edible coatings.

Polysaccharides based edible coating

Polysaccharides are a type of polymer that occurs naturally and is used to make edible coatings. Starch, gums, and chitosan are some of the basic ingredients utilized in polysaccharide-based coatings for food preservation. The use of these coatings has several advantages, including cheap cost and greater availability. Despite the fact that different polysaccharides have lower water vapor barrier qualities, polysaccharides such as alginate and carrageenan are particularly hygroscopic and have thick film qualities. Antioxidants and antibacterial characteristics are found in the polysaccharide-based edible covering. It is effective in keeping fruits and vegetables and also increases their quality. Due to hydrophilic nature, these molecules cannot act as a moisture barrier.[32] Polysaccharide based edible applications on food products are summarized in Table 1.

Starch

Starch is a natural polymer, composed of amylose (water-soluble) and amylopectin (water-insoluble) molecules, having a helical linear structure of glucose molecules capable of forming strong gels. Starch is derived from different sources including wheat, corn, potatoes, and rice etc.[47] Starch-based coating is a potential substance for enhancing the storage life of fruits that is conveniently accessible at a cheap

Table 1. Polysaccharide based edible applications on food products.

Fresh product	Type of coating	Bioactive components/ Additives	Advantages	References
Banana	Chitosan		Delay changes in acidity, pH and weight loss. Prevention from microbial decay. Maintain sensory qualities during storage.	[33]
Pineapple	Cassava starch	Calcium lactate	Effective in reducing weight loss and respiration rate. Improve overall quality attributes.	[34]
Apricot	Chitosan		Extend shelf life. Maintain the antioxidant activity and total phenolic content.	[35]
Cherry	Aloe vera gel		Reduce the respiration rate and retain firmness. Better retention of sensory qualities. Increase phenolic content and antioxidant potential.	[36]
Blackberries	Pectin	*Bacillus methylotrophicus* bm47	Increase storage life. Prevent from fungal decay. Reduce changes in pH, acidity and phenolic content during storage.	[37]
Plum	Alginate	Glycerol	Prevent weight loss, slow down process of softening and retard production of ethylene. Preserve nutritional and sensory attributes.	[38]
Apple	Arabic gum		Protect against microbial decay and keep its quality attributes during storage. Reduction in microbial growth as compared to control.	[39]
Table grapes	Xanthan gum	Ascorbic acid, Citric acid	Preserve the quality attributes during storage. Reduction in weight loss and respiration rate.	[40]
Persimmon (sliced)	Pectin coating	Citric acid, calcium chloride	Inhibit growth of microorganism (psychrophilic aerobic bacteria, yeast and mold). Retard browning process. Extend shelf life.	[41]
Tomato	Guar gum	Glycerol	Reduce the water loss, retain firmness and other quality attributes. Retard change in acidity and soluble solids during storage.	[42]
Carrot	Chitosan	Calcium salt	Maintain sensorial characteristics. Prolong the shelf life. Reduce chances of decay.	[43]
Pumpkin	Starch	Carvacrol	Improve the quality attributes. Decrease in mass loss and acidity loss. Inhibit bacterial, yeast and mold growth.	[44]
Pepper	Pullulan	*Satureja hortensis* extract	Retain color, firmness and nutritional qualities. Reduce weight loss. Prolong the shelf life.	[45]
Cucumber	Arabic gum		Decrease weight loss. Preserve the nutritional and other sensory qualities. Enhance the shelf life.	[46]

cost and has features such as antioxidants and antibacterial to improve the visual look of food commodities as described by Jimenez et al.[48] Many natural and modified plant starches are now employed in the preparation of edible films. in An edible coating of cassava starch and native or modified maize was utilized to preserve carotene in pumpkin while drying, and the findings demonstrated that the coating inhibited the degradation of carotenoids in pumpkin by a substantial ($P < .05$) amount, as reported by Lago-Vanzela et al.[49] According to Garcia et al.[50] edible cassava starch coating with the inclusion of the plasticizer potassium sorbate enhances water vapor resistance and reduces the rate of respiration of strawberry fruit, and also improves its quality during storage period. Hernández-Guerrero et al.[51] No need to use year?? found that a starch-based edible coating prolonged the shelf life of mango fruit by up to 15 days. Fruit kept for 10 days at a temperature of 10°C exhibited no negative effects on firmness or color, and enhanced the organoleptic features.

Chitosan

Chitin is a common naturally produced biopolymer found in crustacean exoskeletons, fungal cell walls, and other biotic matter. Chitosan is created via deacetylation of chitin in an alkaline environment.[52] Chitosan is categorized according to its level of deacetylation and molecular weight and its significance stems from its antibacterial characteristics, which work in tandem with its film-forming and cationic capabilities. The capability of chitosan to operate as a natural food preserver has been widely documented based on in vitro investigations as well as direct usage as actual sophisticated food matrix. Chitosan is also a good substance for film formation. Chitosan films exhibit selective gas permeability (CO_2 and O_2) as well as strong mechanical qualities. It also possesses antibacterial and antifungal effects, as well as low toxicity and biodegradability.[53] Khan et al.[54] experimented that when chitosan was combined with antibacterial and antioxidant agents such as monomethyl fumaric acid, it extended the storage life of fresh strawberries from 4 to 8 days by lowering the amount of yeast, microorganisms, and molds. According to Suksamran et al.[55] chitosan may have a substantial drawback that it may be dissolved in an acidic solution and lose its mucoadhesive property due to deprotonation. Guerra et al.[56] investigated the impact of chitosan coated with peppermint essential oil (EO) on the quality of raw grapes. The results showed that coating the produce with a chitosan-based coating increased shelf life by significantly ($P < .05$) lower the fungal infection. Azevedo et al.[57] explored the impact of an edible covering comprised of chitosan and carvacrol on strawberry postharvest quality. The findings revealed that the film significantly delayed the rate of strawberry decay during storage. Furthermore, chitosan coatings for grapes preservation have been used in a number of studies.[58]

Cellulose

It is one of the most prevalent natural polymers on the planet. Cellulose is a linear an-hydro-glucose molecule that may be found in abundance. Because it is composed of 1–4 connected D-glucose molecules, it produces a strong hydrogen-bound crystalline microfiber. Its use is challenging as a covering because of its water insolubility and tightly connected crystalline shape. Some cellulose derivatives like hydroxyl propyl methyl cellulose (HPMC), hydroxyl propyl cellulose (HPC), carboxy methyl cellulose (CMC), and methyl cellulose (MC) can overcome the constraints linked to the original form.[59] According to Khodaei & Hamidi-Esfahani[60] carboxymethylcellulose (CMC) in combination with the *Lactobacillus plantarum* strain inhibited the development of yeast/molds, and inhibited the degradation of ascorbic acid and phenol compounds in fresh strawberry.

Alginate

Alginates are brown algae-derived structural polysaccharides. Alginate has distinct colloidal properties that aid in emulsion stabilization and the preservation of fruit texture. Alginates are often used for a variety of purposes including protective coating for fresh fruits and vegetables.[61] Alginate covering materials are created by combining divalent cations such as Mg, Ca, Al, Mn, and others; serve as excellent gelling agents. Alginate has certain beneficial characteristics, such as shrinkage reduction, moisture preservation, food odor and color maintenance. Alginate is used to make strong edible coatings or films with low water resistance due to their hydrophilic aspect.[62] According to Robles-Sánchez et al.[63] various experiments showed that when alginate was combined with compounds such as ascorbic acid as an anti-browning agent to preserve color stability, it increased the antioxidant potential and was regarded as a safe and effective treatment. Moreover, some experiments suggested that incorporation of compounds such as antifungals improved the anti-fungal activities of fresh produce because antioxidant and antifungal properties were lacking in the coating content. Some researches, like Syafiq et al.[64] experimented that when rosemary extract, which has antiseptic and antifungal activities, was inserted in Na-alginate, showed a good result and an efficient response against postharvest disease, and also sustained the physiological metabolism and quality of fresh produce, and this type of coating showed better results in the retention of sensory deterioration.[65]

Pectin

Pectin is a type of polysaccharide extracted from plants that can be present in vegetables and fruits. It is generally present in citrus peel and pomace of apple. Pectin polysaccharide's structure is very diverse. Pectin is beneficial for fresh produce coating which has low moisture value, but it is not an effective moisture buffer. It has a diverse set of acidic polysaccharides. Pectin polysaccharide structures are very distinct, containing β – 1, 4-liked galacturonic acid residues. Owing to high Degree of Methyl Esterification (DM) () (50%), pectin was utilized as a preservative in jams, jellies, and cakes. Low pectin and high sugar contents were obtained by de-esterification of high amounts of pectin under controlled environments, so, this low-DM pectin is used as food coatings and thickeners. Yossef[66] stated that strawberries covered with pectin slowed the rate of firmness shift, weight loss, and fruit spoilage due to microbe contamination.

Gums

Gums are utilized in the manufacturing of edible coverings for vegetables and fruits due to their texture. The word "gum" refers to a class of naturally occurring polysaccharides that have worldwide industrial uses due to their capacity to shape gels, create viscous solutions, and stabilize emulsion systems.[67] Xanthan gum is synthesized by a fermentation process which require microbial extraction. It spreads swiftly in water because of its high viscosity and may be utilized in both hot and cold phases. Under adverse circumstances, *Xanthomonas campestris* synthesizes xanthan gum as an exopolysaccharide, which is a Generally Recognized as Safe (GRAS) molecule (FDA).[68] Sharma and Rao[69] explained that addition of an antimicrobial agent like cinnamic acid to xanthan gum significantly delayed oxidative browning, decreased ascorbic level, and declined antioxidant ability of fresh-cut pears, and extended shelf life up to 8 days. Gum arabic is a polysaccharide utilized in food industries as coating, thickener, emulsifier, beverage because of its antioxidant capacity and antifungal characteristics against fungi and other pathogenic bacteria.[70] Tahir et al.[71] described that gum arabic coating with 15% was more favorable in extending the storage life of fruit by delaying or maintaining fruit quality and biological means of conserving strawberry fruit in cold storage. Guar gum is derived from the seed endosperm of *Cyamopsis tetragonolobus*. Because of its nontoxic nature, high mechanical ability, and antibacterial properties, it is used as thickening agent and packing material.[72] According to Minh et al.[73] guar gum, as a surface ingredient, increased the storage life of fresh produce without affecting consistency qualities such as weight loss, firmness, and total soluble solids (TSS).

Protein based edible coatings

Edible coatings based on protein come from plants and animals. Plant-based protein coating materials include zein (source: maize), soy protein, gluten (source: wheat), and so on, while animal-based protein sources include whey protein, milk protein casein, egg albumin, and gelatin. It has a considerably higher potential for constructing a barrier against mechanical strength, organoleptic and aroma retention, and high oxygen permeability, but it lacks a moisture barrier due to its hydrophilic characteristics, which may be strengthened by the introduction of hydrophobic substances such as lipids. Protein based edible coatings on fresh produce are summarized in Table 2.

Corn zein

Zein is the corn storage protein, accounting for 45 to 50% of the protein in corn. When compared to other protein-based coatings, zein-based coatings have reduced water vapor permeability.[7] Zein coatings have even been applied in order to control undesired seed germination. When broccoli and sugar beet seeds were treated with a light zein covering, they germinated later and more slowly. The

Table 2. Protein based edible coatings on fresh produce.

Fresh product	Type of coating	Bioactive components/ Additives	Advantages	References
Apple	Whey protein isolates (WPI)		Prevent weight loss and reduce respiration rate. Maintain firmness and color. Enhance shelf life.	[74]
	Zein	propylene glycol	Zein coating with propylene glycol function as gas barrier. Prevent weight loss and retard browning process.	[75]
Strawberry	Wheat Gluten	Glycerol	Maintain firmness and sensory qualities. Improve shelf life. Reduce fungal decay.	[76]
	Gelatin	Grapefruit seed extract	Gelatin coating with addition of grapefruit seed extract extend shelf life while keeping the sensory qualities of fruit. Inhibited microbial spoilage.	[77]
Pears	Zein	Oleic acid	Better properties as gas barrier. Delayed the respiration rate and weight loss. Prolong the shelf life.	[78]
Melon (sliced)	Soy protein	Lemon extract	Reduction in respiration rate, weight loss and Vitamin C loss. Prevention from microbial decay. Maintain sensory qualities.	[79]
Apricot	Zein	Potassium sorbate, ascorbic acid	Prevent moisture and acidity loss. Protect against microbial growth. Improve the storage life	[80]
Freshly-cut egg plant	Soy protein	Cysteine	Enhance the shelf life. Decrease weight loss, maintain color, firmness and control enzymatic browning.	[81]
Tomato	Egg white	Blueberry extract	Coating of gelatin with blueberry juice preserved the quality attributes. Inhibit microbial decay and extend shelf life.	[82]
Pumpkin	Zein	Benzoic acid	Inhibit the microbial growth. Maintain the physiochemical properties. Increase the shelf life.	[83]
Carrots	Casein	stearic acid	Retain firmness and sensory qualities. Prolonge the shelf life.	[74]

covering's inhibited moisture permeability was responsible for the delayed germination.[84] Baysal et al.[85] conducted a study by dipping intermediate moisture apricots in natural corn protein zein and observed that the corn zein coating reduced microbial growth and color alterations. Park et al.[86] demonstrated that corn zein coating reduced the weight loss and improved the shelf life of pears and apples.

Soy protein

A variety of globular proteins make up soy protein. About 90% of soy proteins are classified as 2S, 7S, 11S, or 15S relying on sedimentation coefficient and molecular weight (Cho & Rhee).[87] Soy protein isolate (SPI) coverings comprising Cys have been proven to assist in reducing enzymatic browning of fresh-cut eggplants to a larger extent than Cys alone and enhance the storage life up to 9 days.[88] Amal et al.[89] observed that strawberries treated with thymol carried by white gluten or soy protein did not alter their appearance till 9 days after packing. Alves et al.[90] explored the use of ferulic acid in soy protein-based edible coatings to improve the quality and storage life of freshly sliced apples. During 7 days of storage at 10°C, the characteristics of freshly sliced apples were examined. The final findings showed that edible films made of soy protein have the potential to enhance the storage life of fresh sliced apples.

Wheat gluten

Gluten is a protein exist in wheat and similar cereals such as rye and barley. Gluten (wheat seed protein) is a biodegradable and renewable alternative. Wheat gluten protein is a versatile resource that may create a fibrous network, resulting in stiffness, flexibility, and ductility in film when composited with glycerol.[90] Tanada-Palmu & Grosso[91] described that coating strawberry with wheat gluten can preserve the fruits from moisture loss, delay the senescence process, increase firmness retention, prevent weight loss, and postpone fruit contamination. Tanada-Palmu & Grosso[91] studied the impact of a wheat gluten-based edible coating on the quality and life-span of refrigerated strawberries. Physicochemical properties like TSS, titratable acidity, weight loss, and sensory attributes were assessed. The results showed that wheat gluten and lipid (stearic acids, beeswax) composite had a significant effect on the weight loss reduction, decreased firmness loss, and improved overall physicochemical results. Wheat gluten edible covering, according to Mujica-Paz & Gontard[92] would be particularly beneficial for fresh food preservation under controlled atmospheres.

Whey protein

Whey protein is a by-product of the cheese making procedure that stays inside the serum of milk after coagulation of casein at a pH of 4.6 and a temperature of 20°C. Whey protein varies casein because negative charge is evenly distributed across protein chain.[93] Whey protein isolates (WPI) are a purified type of whey protein. WPI can act as a carrier for a variety of substances including antibacterial agents. This allows increase in storage life and the improvement of packaged food safety by retaining high concentrations of the active component on the food surface for a longer length of time.[94] Whey protein edible films, according to Hong and Krochta[95] are colorless, flexible, transparent, and flavorless, with reduced oxygen permeability. According to Soazo et al.[96] when whey protein was coated on strawberries, they were preserved by freezing the wrapping material to avoid weight loss after thawing and to retain all quality criteria during quick freezing. Hassani et al.[97] developed an edible coating based on whey protein concentrate (WPC) and rice bran oil. A composite film of WPC and rice bran oil with the inclusion of plasticizers such as glycerol maintained the color, taste, firmness, and overall acceptability of the kiwi-fruit during 28 days of storage.

Casein

Casein accounts for about 80% of the entire milk protein. Casein coatings are translucent, flavorless, and flexible, making them appealing for use in food products. They are used as an edible covering for fresh produce to improve their quality like cellulose and pectin-based coatings.[98] Casein is often utilized in the manufacturing of emulsions due to its amphipathic characteristics and the presence of lipophilic and hydrophilic ends. The most common casein form is caseinate, which dissolves easily in water. Because edible coatings of casein are easy to manufacture, they might be utilized primarily for edible coatings due to their open secondary composition.[99] Villafañe[100] applied coating of casein in combination with turmeric and used Tween 80 (polysorbate 80) as an emulsifier on carrots and observed that color, carotenoid concentration, and antimicrobial properties, as well as texture retention, remained acceptable for 10 days of storage. Lerdthanangkul & Krochta[101] coated the bell peppers with sodium caseinate to delay color change, moisture loss, and extend the storage life.

Egg albumin

Egg albumin is an excellent protein source for coating and film production. Egg albumin comprises half of egg white portion, which includes four free sulfhydryl groups. The capacity of egg white to form films is related to the existence of random coil polypeptide, as well as inter and intramolecular S-S bonds and SH groups.[102] Because of the chaotic structure of denatured proteins in (albumen), it is exceedingly fragile. The inclusion of plasticizers, such as glycerol, lowers intermolecular pressures in the protein chain while increasing mobility and flexibility in the protein-polymer chains.

Lactobacillus acidophilus was preserved by electro spraying and fluidized bed drying with an egg albumen and stearic acid coating (Pitigraisorn et al.[103] Egg albumin based edible coating can be utilized to retain the quality of fresh produce.[104,105]

Gelatin

Gelatin is made by denaturing a protein called collagen (present in the bones, skin, and connective tissues of animals and fish), and it contains a high concentration of amino acids such as proline, glycine, and hydroproline. It has greater thermal stability. Industrial processes involve one or more gelatin types based on the extent of collagen cross-linking in the primal material, which is determined by a variety of factors: tissue type, collagen type, species, animal size, etc.[106] According to research on processing and capability of films using fish gelatins have shown excellent film-forming characteristics, like considerably transparent, water soluble, almost colorless, and able to form extremely extendable film.[107] The major problem with gelatin films is their hygroscopic quality, which causes them to swell or disintegrate when they come into touch with the surface of moist foods. As a result, recent developments are more concentrated on the formation of gelatin films with increased water resistance. The water barrier and mechanical properties of fish gelatin can be upgraded by the incorporation of polysaccharides, proteins, and lipids. Developing material blends, such as oils or waxes, to increase the lipophilic regions in gelatin films may minimize water vapor permeability (WVP) and water solubility.[108] Mannucci et al.[109] demonstrated that a gelatin based edible coating extended the life-span of Fuji apples. Poverenov et al.[110] applied a composite chitosan–gelatin (CH–GL) coating on red bell peppers and investigated the effects on fruit quality and shelf life. The findings indicated that composite coating (CH–GL) was linked to the reduction of microbial growth by two folds, increased fruit texture without affecting the nutritional profile of the fruit and extended the storage life of bell peppers up to 14 days and cold storage up to 21 days.

Lipid based coatings

Edible coatings based on lipids comprise acetylated mono glycerides, waxes, vegetable oils or minerals which give fresh produce a lustrous and glossy look. Because lipid coatings are hydrophobic, so they can assist to lessen the impacts of oxygen, water, light, and other environmental conditions on product quality during storage, as well as decrease the rate of water evaporation from the food item. Furthermore, they defend against chilling harm which mostly occur at cold storage.[111] Lipid based edible application on fresh produce are summarized in Table 3.

Waxes

Waxes are of different types. Some commonly used waxes are discussed in this section.

Carnauba wax

Carnauba wax (CW) is the toughest commercial natural wax and has the highest melting point. It is least soluble wax and is primarily composed of aliphatic esters and diesters of cinnamic acid. It is derived from the leaves of the Brazilian palm carnauba (*Copernicia prunifera*). It is employed in food as a carrier, glazing agent, acidity regulator, bulking agent, and anticaking agent in surface treatment, among other aspects.[126] Nasirifar et al.[127] explored the impact of a carnauba wax coating combined with 2% montmorillonite nano-clay on the storage life and freshness of blood oranges. The coating application improved antioxidant activity, total acidity, firmness, total phenolic content, and the color characteristics of fruit kept at 7°C for 100 days.

Table 3. Lipid based edible application on fresh produce.

Fresh product	Type of coating	Bioactive components/additive	Advantages	References
Avocado	Carnauba wax		Decrease in mass loss, retain color, firmness, without causing off flavor. Increase the shelf life and delay the ripening process.	[112]
	Candelilla wax	Ellagic acid	Candelilla wax coating with addition of ellagic acid increase the shelf life and other nutritional and sensorial characteristics of avocado.	[113]
Mandarin	Beeswax	Oleic acid, triethanolamine	Reduce respiration rate and weight loss. Inhibit microbial decay. Increase the shelf life.	[114]
Apple	Cinnamon EO		Antioxidant potential was increased. Reduce microbial growth. Maintain acidity, color and firmness during storage.	[115]
Strawberries	Candelilla wax	*Bacillus subtilis* HFC103 strain	Candelilla wax with inclusion of *Bacillus subtilis* HFC103 strain controlled growth of *Rhizopus stolonifer and extend the shelf life of strawberry.*	[116]
	Salvia officinalis EO		Protect against fungal decay. Maintain color and sensory characteristics. Prolong the shelf life.	[117]
	Cumin essential oil		Discoloration retention. Delay incidence of fungal decay and color changes. Increase the shelf life.	[118]
Nectarines	Carnauba wax		Delay fungal growth. Increase postharvest life. Improve firmness and brightness of fruit.	[119]
Pears	Beeswax	Oleic acid, triethanolamine	Maintain pH, acidity, total soluble solids and phenolic content. Increase the shelf life.	[120]
Tomato	Carnauba wax		Reduce change in pH, soluble solids and color. Maintain sensory qualities. Delayed chlorophyll degradation.	[121]
Sweet Potato	Carnauba wax		Preserve the sensory and nutritional attributes. Delay mass loss, color change and microbial growth.	[122]
Bitter gourd	Carnauba wax		Minimize respiration rate, weight loss and prevent from microbial spoilage. Extend storage life.	[123]
Tomato	Beeswax	Neem leaf extract	Reduce weight and firmness loss. Inhibit microbial deterioration. Maintain color, taste and flavor during storage.	[124]
Jujube fruit	Carnauba wax	Glycerol monolaurate	Delay microbial spoilage. Prolong the shelf life, reduced respiration rate and water loss. Preserve sensory qualities during storage.	[125]

Paraffin wax

Paraffin wax (PW) contains a solid hydro-carbon and is made from a portion of crude petroleum. It has a limited application on raw fruits and vegetables, but it acts as a moisture barrier and gives a shiny, glossy appearance.[128] It is white, tasteless, odorless, waxy solid, and has a melting point of 46–68°C. It is insoluble in water but soluble in benzene, ether, and certain esters. Most typical chemical reagents have little effect on paraffin, yet it burns easily. Bahnasawy & Khater[129] studied the impact of paraffin wax coating on cucumber fruit. The main outcomes showed that it increases the shelf life of cucumbers and this increase is related to in wax solution consistency and storage temperature. The quality and storage life of the aforementioned fruits have been discovered to be significantly improved by covering them with an edible coating. Since 1930s, China has been coating apples and pears with hot-melt paraffin wax. However, many laws prohibit the use of paraffin wax as an edible covering.

Bee's wax

It is obtained from honeybee. Bee's wax coating aids in the maintenance of quality attribute such as moisture and gas permeability resistance, and the enhancement of functional characteristics such as physical and mechanical properties of the edible films.[130] According to Mandal et al.[131] beeswax, poly-L-lysine, or stearic acid, were used as exterior coatings of probiotic microcapsules produced with resistant alginate and starch. They concluded that under simulated gastrointestinal circumstances, microcapsules coated with beeswax and stearic acid increased the survival rate of encapsulated *Lactobacillus casei* probiotic cells.

Candelilla wax

Candelilla wax (CW) is made from the leaves of a tiny plants (*Euphorbia antisyphilitica* and *Euphorbia cerifera*) found in southwestern USA and northern Mexico. The usefulness and effectiveness of candelilla wax as a constituent in edible films to enhance the storage life of fresh produce has been addressed in a number of studies.[132] Oregel-Zamudio et al.[133] demonstrated that the effect of candelilla wax edible films in conjunction with *Bacillus subtilis HFC103* is a novel approach that can extend strawberry storage life.

Cactus mucilage

Mucilage made from the cladodes of the cactus pear (*Opuntia ficus-indica*) has a highly branching, complex polymeric carbohydrate structure with changing amounts of L-rhamnose, L-arabinose, D-xylose, and D-galactose.[134] According to Del-Valle et al.[135] fruit color, firmness, weight loss, fruit respiration rate, and fungal infection were all reduced when O. ficus-indica mucilage was applied to fresh strawberries.

Essential oils (EOs)

Aromatic plants produce EOs, a secondary metabolite with a wide range of biological activities. EOs are generally regarded as safe (GRAS) by the American Food and Drug Administration.[136] It can be utilized as a potential alternative to synthetic additives. On the other hand, EOs are frequently lipophilic and volatile, as well as being almost water insoluble. EOs in combination with antimicrobial agents like flavonoids, isoflavones, alkaloids, phenolic acids, terpenoids, aldehydes, and carotenoids have shown promising results.[137] Essential oils have been shown to be efficient antibacterial agents. However, due to their volatility, their use for preserving fruit quality and delaying fungal rot is restricted. As a result, EOs must be encapsulated in a food-safe conveyance system in order to retain their biological pursuit, boost their effective usage rate, and reduce their effect on food organoleptic qualities.[138]

Thymol

Thymol (Thy) is a natural essential oil that has been certified as "generally regarded as safe."[139] It has been widely used as aromatic spice in culinary preparations, antioxidant and antifungal agent against *Botrytis cinerea*.[140] The usage of thymol as an antifungal agent has significant downsides, including a strong odor, limited water solubility, and high volatility, all of which reduce its antibacterial efficacy over time.[141] They have such great promise as a natural antifungal addition, researchers have concentrated their efforts on overcoming these disadvantages.[142] Rahimi et al.[143] studied the impact of three distinct coatings; 0.5% chitosan, 200 mg L^{-1} essential oil (thymol) and their composite use on postharvest quality of peach. As a control, the fruits were dipped in distilled water. After several days of storage at 6°C, changes in weight loss, TSS, fruit hardness, decay incidence, carotenoid and anthocyanin content, sensory characteristics of fruits were assessed. Results revealed that the combined application of chitosan and thymol had a more significant preservative effect than chitosan or thymol coatings alone. Weight loss, TSS, and fungal decay, were much lower in the coated fruits with 0.5% chitosan + 200 mg L^{-1} thymol than in the control treatment. Furthermore, chitosan + thymol composite-coated fruits had considerably higher firmness, carotenoid and anthocyanin content, and sensorial characteristics than untreated control fruits. Likewise, the maximum storage life (28.33 days) was also noticed in chitosan and thymol treated fruit.

Lemongrass oil

The primary components of lemon essential oil, which is derived from citrus lemon, limonene, ocimene, and valencene.[144] Lemongrass oil (LO) exhibits an antibacterial effect against gram-positive and gram-negative bacteria, as well as against yeast and mold.[145] According to Yousuf et al.[146] the lemongrass EO-edible coating could successfully prevent yeast growth. Praseptiangga et al.[147] found that a cassava starch-based edible covering integrated with 1% lemongrass can be utilized as a substitute for papaya preservation. The addition of lemongrass EO remarkably suppressed the microbial activity by lowering the value of mold and yeast. Perdones et al.[148] stated that adding lemon essential oil increased the antifungal action of chitosan film and was helpful in enhancing the storage life of strawberries.

Lavender essential oil

Lavender essential oil has been used as a medicinal treatment for decades, produced from the common herb Lavender (*Lavandula spp*.). In addition to its antibacterial characteristics, the oil is said to have carminative, sedative, anti-inflammatory, and anti-depressant effects.[149] *Botrytis cinera* inhibitors can also be mitigated by lavender essential oil.[150] Sangsuwan et al.[151] explained that adding lavender essential oil in chitosan film improves the storage life of strawberries and has the ability to inhibit the effect of *Botrytis cinerea* that can spoil strawberries.

Cumin essential oil (CEOs)

Cumin (*Cuminum cyminum*) is a tiny, annual herbaceous plant in the Umbelliferae family. Due to its unusual scent, it is often used as a spice and flavoring ingredient. Cumin is used as an astringent, carminative, and stimulant in veterinary and traditional medicine to treat gas, diarrhea, and indigestion.[152] Oyom et al.[153] developed an edible film by incorporating cumin (EO) into (modified) sweet potato starch. The coating's impact on the physiochemical and sensory attributes of "early crisp" persevered for 28 days at a temperature of 25°C was studied. The study found that cumin (EO) and potato starch composite was effective to maintain the internal quality and stomatal densities of "early crisp." Furthermore, the starch with CEOs of 0.2 and 0.4% efficiently inhibited color changes, firmness decline, water loss, and rotting in pear induced by *Alternaria alternata*. Cumin essential oil doses in the coating had no negative effect on the pear's organoleptic qualities, but they actually enhanced the physicochemical characteristics and kept the pear palatability and acceptability after 28 days of storage. In a study by Asghari et al.,[118] coating strawberries with cumin oil had shown to increase their shelf life and had a significant impact on preventing the fungal infection by *Botrytis cinerea* without compromising their quality characteristics.

Cinnamon essential oil (CEO)

Cinnamon is made up of resinous components as well as essential oils like cinnamaldehyde, eugenol, camphor, linalool, b-caryophyllene, and other terpenes and terpenoids.[154] Cinnamon essential oil helps to prevent gray mold and *Rhizopus rot*, both of which can deteriorate strawberry fruit.[155] CEO obtained from the bark was superior to that from the leaf in terms of antibacterial activity and sensory aspect when used in strawberry shakes.[156] CEO is responsible for the distinctive odor and flavor, but its composition varies depending on the sections of plant it is derived.[157] According to recent research by Ju et al.,[158] an edible coating comprising cinnamon essential oil (EO) can significantly ($P < .05$) minimize ham oxidation and microbial activity during preservation. Khorram, & Ramezanian[159] investigated the efficacy of shellac-based edible covering integrated with CEO on quality of oranges regarding weight loss, fruit deterioration, hardness, ascorbic acid (AA), and sensory attributes. Shellac coating (10%) with 0.5% CEO lowered firmness decline by 38% and weight loss by 52%. The findings suggested that including CEO in shellac would be a good way to keep citrus fruit quality. Tabaestani et al.[160] explored the impact of a promising edible film containing basil mucilage, cumin essential oils, and a composite of basil mucilage and cumin essential oils on the quality of tomatoes. Treated and untreated fruit were kept at a relative humidity of 80–90% at a temperature of 20°C. The findings revealed that essential oil-coated treatments and gum-coated treatments exhibited better results than untreated fruits and gum-coated treatments at the end of the allotted period.

Salvia officinalis essential oil

Salvia, the Lamiaceae family's biggest genus, has over 900 species worldwide, some of which are commercially important because they are used as spices and flavoring ingredients in cosmetics and perfumery. These plants are mostly cultivated in South Brazil. According to an investigation of the essential oil composition of many Salvia species shows that borneol and 1,8-cineole (eucalyptol) are its primary ingredients. Nabigol[117] stated that coating of Salvia officinalis oil on strawberries results in the extension of shelf life as well as a reduction in the fungal infection.

Vegetable fat

Vegetable oils (sunflower oil, olive oil, rapeseed oil, maize oil) are widely accessible, inexpensive, nonvolatile, non-depletable, nontoxic, and a source of monounsaturated fatty acids, therefore, their use as an edible coating on food items has been linked to a variety of health advantages.[161] Hasan et al.[162] created a unique starch based edible film that incorporated olive oil (extra virgin). Various physicochemical properties as well as antioxidant and antibacterial potential of film was investigated. The finding revealed that film surface roughness was decreased but the elongation at break and tensile strength were enhanced significantly. Silva et al.[163] described that probiotics microencapsulation utilizing either vegetable oil as the primary protective film or gelatin-gum arabic as the cover material preserved the probiotic cells in simulated gastrointestinal and stress circumstances compared to unbound cells.

Composites based edible coating

Recently, there has been a great attention in the creation of bilayer or composite coatings that include polysaccharides, proteins, and/or lipids for improved coating functional quality. Because each single coating material has a distinctive but restricted purpose. When two distinct types of coating substances are combined, the functionality can be improved. The primary function of composites is to get more benefit by highest achievable performance of the mixture while keeping the qualities of the individual components as stable. Combining multiple materials can result in creation of composite edible coatings with unique features. Composite based edible coatings on fresh produce are discussed in Table 4. Composites coatings are categorized as: (i) Binary films and coatings,[175] (ii) Ternary edible films and coatings,[176] and (iii) Quadruple edible films and coatings[177]

Binary films and coatings

Bilayer composites are made up of two layers that are coated with the same or differing materials such as polysaccharides/polysaccharides, protein/protein, polysaccharides/protein, polysaccharides/lipid, and lipid/lipid.

Polysaccharides/Polysaccharides: To create a bi-layered edible film, carrageenan was mixed with rice starch. Plasticizers such as glycerol and stearic acid were utilized with varying quantities of biopolymers. Moisture content, solubility, color characteristics, and water vapor permeability were

Table 4. Composite based edible coatings on fresh produce.

Food items	Type of composite	Bioactive components/ Additives	Advantages	References
Citrus fruit	HPMC + bees wax	Glycerol, GRAS salt	Retention of weight loss, restrict changes in acidity and soluble solids content. Maintain sensory qualities. Prolong the shelf life. Prevention from fungal decay.	[164]
Jujube fruit	Pectin + Aloe vera gel		Decrease respiration rate and weight loss. Increase shelf life. Reduce alterations in ascorbic acid content, acidity, pH and soluble solids content than control.	[165]
Melon (sliced)	Alginate + Cinnamon + lemongrass EO		Maintain quality characteristics. Reduced mass loss and improve shelf life. Inhibit microbial growth.	[166]
Peach	Pectin + Cinnamon EO	Glycerol	Increase antimicrobial and antioxidant activity. Reduce microbial growth. Prevent changes in color, taste and flavor during storage.	[167]
Mango	HPMC + bees wax + ginger EO	Nanoclay	Preserve sensory qualities. Maintain pH, acidity and soluble solids content during storage.	[168]
Guava	CMC + Cashew gum	Glycerol	Delay softening process. Retain firmness and color. Reduce weight loss and microbial decay.	[169]
Blueberries	Chitosan + quinoa protein + Sunflower oil		Decrease weight loss and respiration rate. Maintain pH, soluble solids content and acidity during storage. Control microbial growth. Prolong the shelf life.	[170]
Mulberry	Cassava starch + chitosan		Retard microbial growth. Improve shelf life. Higher anthocyanin content and antioxidant potential than control. Better retention of sensory qualities.	[171]
Bell pepper	Chitosan + gelatin		Prolong the shelf life. Retain nutritional content. Reduction in microbial growth compared to control.	[172]
Carrot (sliced)	yam starch + chitosan	Glycerol	Prevent the attack of yeast and mold. Improve the quality characteristics of fruit. Enhance shelf life.	[173]
Cucumber	Chitosan + Aloe vera gel		Delay ripening process. Prevention from microbial attack. Prolong the shelf life. Reduce changes in soluble solids and ascorbic acid content during storage.	[174]

[169] Forato, L. A., de Britto, D., de Rizzo, J. S., Gastaldi, T. A., & Assis, O. B. 2015. Effect of cashew gum-carboxymethylcellulose edible coatings in extending the shelf-life of fresh and cut guavas. *Food Packaging and Shelf Life*, 5, 68–74.

among the model parameters investigated. Furthermore, biopolymer interactions were studied utilizing sophisticated characterizations such as X-ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR). According to the findings of the investigation, the combination method increased tensile strength and elongation at break qualities. In the meantime, FTIR studies revealed that band shifting between 1200 and 1300 cm^{-1} could be the result of polysaccharide interactions as described by Thakur et al. (2016). Chitosan nanoparticles were cross-linked with tara gum then exemplified for host issues like barrier and antimicrobial properties as thermomechanical. FTIR, and XRD, thermogravimetric analysis (TGA) were used to investigate molecular interactions and heat stability. The addition of chitosan nanoparticles resulted in rough surface consistent distribution. In addition, tensile strength and antimicrobial activity also increased as demonstrated by Antoniou et al.[178] According to Rao et al.[179] the use of 85% chitosan coupled with 15% guar gum exhibited a good response in improving mechanical properties as well as minimizing oxygen permeability.

Protein-protein: A bi-layer edible film was created by combining SPI and corn zein isolate for the covering of olive oil condiments. The physical and oxidative stability qualities of olive oil laminates were analyzed. A comparison was made between the bilayer and monolayer controls, which concluded that the inclusion of corn zein improved tensile strength and moisture barrier.[175] According to Vachon et al.[180] strawberries encapsulated with milk proteins such as caseinate and whey protein by irradiation result in reduced fruit contamination and improved overall quality attributes of fruits. Gelatin and barley bran protein were used to create the composite film. According to Song et al.[181] gelatin, barley bran protein was used to create the composite film. Tensile strength and elongation at break were assessed as mechanical characteristics. Because of its strong film-forming capacity, the study deduced that barley bran protein could be a good selection. 3% gelatin, 3% barley bran protein, and 1% plasticizer were used to get the best film conditions. Furthermore, using salmon as a model food, this composite film was mixed with grapefruit seed extract to evaluate antioxidant and anti-bacterial effects. When compared to a control preparation, the number of *Listeria monocytogenes* and *E. coli O157:H7* was reported to be considerably lower. Additionally, the levels of Thiobarbituric acid reactive substances (TBARS) and peroxide decreased by 23.4 and 23%, correspondingly.[182]

Protein-Polysaccharides: Recently, there has been a lot of interest in the development of composite edible films (chitosan/gelatin) with antimicrobic extracts to improve storage life. Many ethanolic compounds of rosemary, cinnamon, boldo-do-Chile, and guarana, having antioxidant and antibacterial characteristics were used with the gel-forming solutions. Mechanical, structural, optical and barrier properties were investigated. Enhanced chitosan incorporation resulted in increased flexibility and decreased water vapor permeability of these films. The bio-active composites inhibited *E. coli* and *S. aureus*, demonstrating superior antibacterial characteristics, while the Trolox-Equivalent-Antioxidant-Capacity test (TEAC) revealed excellent antioxidant potential as described by Bonilla and Sobral[183] According to Abugoch et al.[184] quinoa protein (anionic) and chitosan (cationic) extract were mixed by a liquid casting approach. Bilayer film, which is made from a blend was categorized for film mechanical strength and microstructure. The film was assessed for sorption testing. Improvements in mechanical strength were attained by bilayer (combination of quinoa protein and chitosan) in analytic methods like TGA, XRD, and FTIR. Results revealed that the obtained bilayer film acquired a more hydrophilic nature as related to chitosan. Fakhouri et al.[77] investigated the capability of gelatin coatings comprising cellulose nanocrystals (GEL/CNC) to prolong the storage-life of strawberries. Results indicated that fruits coated with GEL/CNC had a great improvement in storage life over 8 days. Furthermore, the use of GEL/CNC coating had an antimicrobial impact on fruit and was also efficient in maintaining ascorbic acid.

Lipid-lipid: The impacts of β-glucan-fatty acid esters on microstructural, physical, and barrier properties were studied by Podshivalov et al.[185] β-glucan was combined with numerous hydrophobic unsaturated and saturated fatty acids to create equivalent β-glucan-fatty acid esters with almost uniform degree of interaction. A film was formed by combining palm kernel olein and palm stearin (1:1) and was applied to guava to see how it affected the fruit's quality during storage, and also compared fruits coated with beeswax to those coated with palm kernel olein and palm stearin film. When compared to beeswax coating, the findings showed that palm kernel olein and palm stearin bilayer films exhibited higher cohesiveness. This bilayer film also prevented weight loss, yellowness, and slowed the falloff lightness, glossiness, and guava greenness at 21 days of storage temperature (20°C), and showed promising results in maintaining fruit quality as compared to being covered with beeswax, as studied by Ruzaina et al.[186]

Polysaccharides-lipid: Tara gum was used to make edible films, and oleic acid was combined with it to increase its hydrophobic properties. Oleic acid concentrations in gum base ranged from 0–20% w/w. According to FTIR measurements, no link was formed between oleic acid and tara gum molecules. It was also observed that oleic acid reduced the strength of hydrogen bonds among gum molecules. The study found that adding oleic acid to edible films resulted in non-homogeneous systems, which resulted in lower transmittance and tensile strength. The moisture barrier attributes of films were found to be increased by oleic acid. It also resulted in a film that had a substantial impact on the thermal characteristics of the film, as described by Ma at el.[187] Eshetu et al.[188] experimented that when a coating of chitosan and bees-wax was applied to the sample, it preserved the fruit's quality by avoiding contamination, and it also allowed it to be carried over longer distances since the coated samples kept their freshness without losing any of their qualitative traits. Corn starch coating with the addition of sunflower oil increase the shelf life of strawberries and reduces water loss and improves antimicrobial activity, maintains selective gas permeability, maintains quality attributes of fruit without any damage, as described by García et al.[189]

Protein-lipid: Adding sunflower oil to cod gelatin at different concentrations: 0.1%, 0.3%, 0.6%, and 1% to increase the hydrophobic nature of protein film. FTIR were used to identified protein-lipid interaction (ester formation and hydrogen bonding) and oil oxidation. By the end of storage, oxidation had progressed to the point that secondary oxidation products were visible. Findings showed that addition of any amount of oil in protein film reduced the puncture force, decreased soluble matter content, and water vapor permeability as well as decreased transparency. Addition of oil to protein film increases its whiteness, thickness, and optical absorbance, as explained by Pérez-Mateos et al.[190] A composite film was made from gelatin and olive oil through a microfluidic emulsification method. The aim of this was to improve the hydrophobic nature and the impact of oil concentration on lipid droplet distributions in film-forming suspensions and emulsified layers was studied and analyzed. The findings indicated that olive oil has a high potential for being mixed into gelatin to create films or coatings for a number of food products. Addition of olive decreases the tensile strength and water vapor permeability and gives shiny look to gelatin film as studied by Ma et al.[191]

Ternary edible films and coatings

A triple-layered edible film was created from soy protein, chitosan, and Konjac glucomannan utilizing plasticizer like glycerol. Water absorption, percentage of elongation, and tensile strength at break were among the physicochemical parameters assessed by Jia et al.[192] Many of the response parameters in the investigation had a wide range of values: for example, water vapor permeability varied from 3.29 to 9.63×10^{-11} gm-^{1} s^{-1} Pa^{-1}. Furthermore, tensile strength varied from 16.8 to 51.1 MPa, and the inclusion of plasticizer decreased tensile strength and water vapor permeability while increasing percent elongation.[192] A multilayer edible layer from pullulan, alginate, and other polysaccharides like carrageenan, pectin, was created by co-drying approach. The qualities of mechanical, physical, optical, and barrier materials were investigated. According to the findings, ternary-co-blended layers can be utilized to preserve multiple kinds of food products.[193] A ternary based films were created using alginate, collagen, and agar. Moreover, antimicrobial agents such as grapefruit seed extract and silver nanoparticles were added to the composite films. According to the Wang and Rhim,[194] such films can drastically reduce *Escherichia* and *Listeria* counts when applied to fresh potatoes as a model food system, Whey protein isolate, sodium alginate and gelatin were blend in different proportion and numerous mechanical characteristics (tensile and tear strength, elongation at break, puncture strength) as well as water and oxygen barrier properties were measured by electron microscopy. Result showed lowest water vapor permeability and oxygen permeability at 48.00 g mm/kPa d m^2 and 8 cm^3 µm/m^2 d kPa. Examining electron microscopy pictures showed that formulations with greater concentrations of gelatin and whey protein had fewer porous structures as compared to other formulations as reported by Wang et al.[195] Addition of Aloe-vera gel in chitosan and banana starch blend has ability to decrease the fungus decay as well as prolong the shelf life of strawberry up to 15 days as demonstrated by Pinzon et al.[196] In a study by Tripathi et al.[197] polyvinyl alcohol (PVA), chitosan, and pectin-based ternary coating/film were made using a solution casting approach. The film's morphological, structural, thermal, and antibacterial properties were examined. The film was found to be rough, crystalline, heterogeneous, and had better antibacterial activity against *S. aureus, Pseudomonas spp., E. coli, Candida albicans*, and *B. subtilis*.

Quadruple edible films and coatings

To create quadruple edible films, methylcellulose and polycaprolactone were combined with antimicrobial chemicals such as organic acids, Asian essential oils, rosmarinic acid, and an Italian essential oil blend. The obtained films were put into broccoli-growing containers and kept at 4°C for 12 days. Both *S. aureus* and *E. coli* considerably inhibited by the antimicrobial films, as reported by Takala[198]

Regulatory aspects

Edible coatings are commonly made from plant and animal products. Because of their ecological friendliness, they have become a popular approach for postharvest processing.[199] Protein, lipids, and polysaccharides are the main ingredients of an edible coating. Several coating materials like cellulose, chitosan, aloe vera, and protein-based polymers have proven exceptional barrier properties as well as outstanding flavor and competent antibacterial action on fruits when combined with an active ingredient. Food packaging material regulations differ from nation to nation. Food packaging materials that are acceptable in one nation may not be acceptable in another. These divergences have a big impact on the quantity of data needed to assess whether a packaging material is appropriate or not for a food product. According to US and European Directive rules, edible films and coatings are classified as food ingredients, food products, food contact substances, food additives, or food packaging substances. Because edible films are regarded as intrinsic components of the food they contain, they must follow all food-related standards. This means that all components that are utilized for making edible films must follow food safety and quality laws and regulations.[200] According to this EU rule, (Regulation (EC) No. 1935/2004), all food-contact ingredients and commodities must fulfil the four fundamental standards: (a) they must be made in accordance with excellent manufacturing practices; (b) they must not alter the food's color, odor, taste, or texture; (c) the material must not have an adverse effect on the composition of food, and (d) it must not endanger to human health. But this regulation does not clearly state the safety assessment of nanoparticles in packaged food and their biological consequences. The United States Food and Drug Administration (USFDA) publishes food component lists and food contact compounds; advises producers to research and test them to develop a toxicological profile of every container having nanomaterials. Commercially accessible fresh produce coatings are mentioned in Table 5. [201]

Future trends

Consumers are getting more sophisticated and they are increasingly interested to seek healthier foods and lifestyles. Balance between demand and supply requires consistent research and enhancement of edible coating techniques.[3] Nonetheless, every technique of development includes flaws and limitations. The key problem which requires future study is extending the storage life of fresh/fresh-cut

Table 5. Commercially accessible fresh produce coatings. Source: Prasad et al. (2018).

Trade Name	Mixture (Composition)	Countries where available
Semperfresh™	Sucrose esters	The United Kingdom (UK)
FreshSeal™	Starch, Polyvinyl alcohol, and surfactant	United State of America (USA)
Nature seal	Calcium-pectinate	USA
Fry shield	Calcium-pectinate	USA
Nutri-save	N, O-Carboxymethyl chitosan	UK
Nature-seal™	Cellulose based coatings	USA, UK
Opta-Glaze	Gluten (wheat)	USA
Z Coat	Protein from corn	USA
Zein	Corn protein (Zein)	USA, UK
Tal Prolong	Composite of sucrose fatty acid esters, mono and diglycerides, sodium CMC	UK
Citrashine	Wax and Sucrose ester	USA
Brilloshine	Sucrose ester and wax	UK
Natural Shine ™ Series	Carnauba, Vegetable wax, and shellac	USA
Shield-Brite® Series	Shellac and Carnauba	USA
PrimaFresh® Series	Vegetable wax, shellac, and carnauba	USA
Sta-Fresh Series	Carnauba/ Resin/ Shellac	USA
Ban-seel, Nu-coatFlo	Sodium salt of CMC & fatty acids ester of sucrose	USA, UK
Syncera series	Shellac resin, carnauba wax, and polyethylene	USA

fruits without compromising their sensory and nutritional properties. Several researches including innovative and cost-effective food packaging for fresh produce are still at early phase of study and at inquiry phase prior to large-scale industrial implementation. The formation of innovative edible coating materials is predicted to come from a detailed examination of biochemistry and its relationships with antimicrobial, physicochemical, and possible toxicity, as well as risk assessment. Primarily, more advancement is needed in terms of coating materials particularly in terms of nutritional value, mineral migration and efficiency, ratio of co-effectiveness, and current technological protocols to ensure and enhance storage life and preserve the quality of coated fresh/fresh-cut fruit.[202] Most studies centered on the tensile strength of edible films. The film qualities must be consistent over time in order to secure contained food and ensure a longer shelf life. However, edible films are prone to deterioration during aging. Only a few research on the effects of aging on film qualities exist in the literature. There is a need to investigate the strategies that regulate time-dependent alternations in film characteristics. Various studies have been presented on the water and gas permeability of edible films or coatings but only a few studies available on aroma permeability, oil permeability and the permeability of additives. Another important sector that requires a large number of packaging materials is beverage industry. Limited studies are available on the use of edible films for beverage packing.[203] Edible films or coatings should be suitable for current packaging technologies. Packaging material commonly serves as a barrier between both the food and its surroundings. Some of the most recent food packaging technologies include active food packaging, intelligent food packaging, and smart packaging.[204] Active packaging offers certain interactions among food and the surroundings.[205] Intelligent packaging keeps track of the food's status and provides data. Smart packing not just to monitor the food, but also enables the customers to track the food and manage its quality aspects. They employ a variety of indicators, sensors, and radio frequency identification systems (RFID). However, incorporating thin film electronic sensors upon edible films and putting these devices into communications networks are major challenges that require more exploration.[206] All these technologies mentioned above are used for preservation of fresh produce referred as "green technologies." Safe or green technologies are those which develop and use to help in preservation of important nutrients by minimizing or completely removing the negative effects associated with food processing.[207] Edible coating manufacturing is still in its early stages and little amounts are produced. The cost of edible coatings is greater than the cost of petroleum-based plastic films. Customers' acceptance of edible films is mostly influenced by the price of edible films. To attract customers, the price of edible films should be lower than or equivalent to the cost of petroleum-derived polymers.

Conclusion

From this comprehensive review, it can be stated that edible preservation technology, also termed "green technology," is a necessity of the present era. In comparison to traditional food preservation methods, these technologies help to prevent food spoilage besides preserving nutritional values. The bio-edible based coating is a more efficient strategy for improving the quality and safety of fresh produce than other techniques currently being utilized. Edible-coatings are a stratum of eatable substance that encapsulates the foodstuff and restricts water vapor, carbon dioxide, and oxygen movement which results in prolong shelf life without affecting its safety and quality parameters. Many food and drug administrations, as well as food safety governing agencies have not only authorized but also set safe limits for edible coatings. That's why, edible coatings and films are gradually gaining traction as viable substitutes to synthetic packaging. Recent work on edible films and coatings has resulted in the creation of many new films but there is still a requirement to pay more attention because there is a huge gap in improving the marketing potential of edible coatings.

Acknowledgments

The authors are grateful to Government College University for providing resources for collecting literature.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The authors declare that no grants, funds, or other assistance were received during preparation of this manuscript.

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