# Biopolymer-based Films and Coatings: Emerging Technologies to Extend Shelf-life of Fruits and Vegetables

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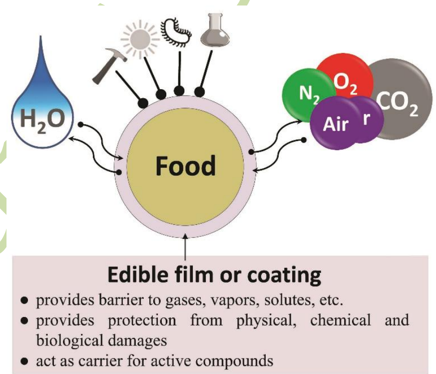
**Abstract**

Worldwide, consumers demand for fresh and chemical free fresh fruits and vegetables are continuously expanding, as these food items are rich in nutrition promoting good health and immunity. The primary challenge to cater to these increasing demands is the fact that fresh produce are perishable commodities, and need effective preservation strategies to successfully mitigate this challenge. Biopolymer based films and coatings have emerged as effective, biodegradable alternatives to their synthetic counterparts. Reinforcement of biopolymers with natural active agents such as essential oils and/or nanomaterials improves mechanical, thermal, barrier, and functional (antimicrobial and antioxidant) properties of these composite films and coatings. Numerous published reports have demonstrated that biopolymer-based films and coatings can effectively reduce weight loss, and postharvest decay such as biochemical and microbial spoilage of coated fresh fruits and vegetables resulting in their postharvest shelf-life extension by a few days to as long as a month. This review is a comprehensive account on applications of biopolymer based active, composite coatings and films for sustainable packaging of fresh produce.




**Keywords:** Composite films and coatings, Postharvest shelf life, Fresh produce, Food preservation, Biodegradable films and coating

## 1. Introduction

Fresh fruits and vegetables are perishable commodities having excellent nutritional qualities, and are considered essential part of healthy diet. About 25-30% of the total production fruits and vegetables in India are lost during postharvest storage, handling and transportation. This is a significant challenge, as it not only affects the growers' income, but also costs the nation's economy dearly. Thus, extension of postharvest shelf-life of fresh produce is of immense importance for growth and prosperity of their farmers, handlers, processors, and to ensure healthy food habits among consumers. Packaging and coating of fruits and vegetables are effective ways to maintain their quality and prolong their postharvest shelf-life. Synthetic plastic polymer based packaging and synthetic-wax based coatings have been profusely used in preservation of these products. However, these synthetic inputs are non-degradable and harmful to consumers and environment. As sustainable alternatives, biopolymers such as polysaccharides, proteins, lipids, either alone or blended with natural active agents and/or nanomaterials, have been extensively studied in recent years[1]. These biodegradable alternatives are obtained from renewable sources such as plants, animals and microorganisms. However, biopolymer-based packaging films suffer from certain shortcomings such as poor mechanical, barrier and thermal properties. Blending more than one biopolymer, reinforcement with natural active agents and /or nanomaterials improve these properties rendering them suitable for fruits and vegetable packaging. Weight loss, postharvest respiration, maturity, senescence, enzymatic and microbial decay are primary causes of quality deteriorations in fresh fruits and vegetables. Physical injuries to fresh produce during harvesting, transportation, storage and handling further accelerate such deteriorations. Numerous studies have evaluated effectiveness of chitosan,[2] gelatin,[3] agar, collagen,[4] whey,[5] starch,[6] cellulose,[7] alginate,[8] and polylactic acid[9] based films and coatings in extending shelf-life of perishable food items, including fruits and vegetables. Plant-based essential oils, other phytochemicals, and nanomaterials are effective antimicrobial and antioxidant agents that can effectively improve functionalities of these active films and coatings. This review is a contemporary account of advancements in applications of these alternative packaging systems for extending postharvest shelf-life of fruits and vegetables.

## 2. Shelf-life of fruits and vegetables

Post-harvest shelf life or longevity of fruits and vegetables is best defined as the period starting from harvesting until the product maintains acceptable quality for consumer. The metabolic processes in fruits and vegetables continue even after harvesting, and postharvest technologies are required to extend their shelf life. Quality of fruits and vegetables depends on the climacteric conditions, preharvest practices, maturity, harvesting methodology, postharvest handling (sorting, sanitization, precooling, and packing) and storage conditions (humidity, temperature, and gas composition).[10] In order to ensure prolonged shelf life, the quality attributes such as nutritive value, flavor, color, odor, and texture should be maintained throughout the food supply chain.[11] Because of high available moisture content, richness in nutrients, and continuous postharvest metabolism or senescence, fruits and vegetables are vulnerable to weight loss, mechanical damage, and microbial attack. These characteristics lead to noticeable deterioration after harvesting and shorten their shelf life. Proper packaging and preservation methods can help extend the shelf life of fruits and vegetables, using appropriate ethylene absorbents and gas scrubbers. The gas composition surrounding the food products such as ethylene, $CO_2$, and $O_2$ adversely impact the respiratory rate. To minimize the spoilage, various active packaging systems incorporated/combined antioxidant or antimicrobial agent, $CO_2$ emitters, oxygen and moisture scavengers, etc. have been applied.[12]

Now-a-days, consumer demand high quality fruits and vegetables, mostly organic, as they are rich in dietary fibers, antioxidants, vitamins, essential minerals, bio-flavonoids, and flavor compounds. After harvest, fruits and vegetables being highly perishable, face significant wastage due to microbial spoilage, insects' infestation, high transpiration and respiration rates. The extrinsic factors include atmospheric conditions such as ethylene ratios, $O_2$, $CO_2$, temperature, relative humidity and stress factors, whereas intrinsic factors include the variety, cultivar and growth stage of fruits and vegetables[10] Microbial spoilage may occur through damage skin resulting in deterioration of fruits and vegetables, for example off flavor, tissue softening, eventually decreasing their quality and make them inedible. Texture, color, appearance, flavor, nutritional value and microbial safety are the important quality factors of fresh produce and they are affected by stage of ripening, degree of maturity, plant variety, pre-harvest and post-harvest conditions.[13] Biopolymers are being explored as sustainable alternatives to synthetic plastics for fabrication of edible films and coating for postharvest shelf-life extension of fruits and vegetables.[1,14] Chitosan, pectin, starch, alginate, carrageenan, and xanthan gum have been commonly used for fabrication of active composite films and coatings.[4,15] These active and edible films and coatings provide safety barrier around the fruits and vegetables that reduce transpiration and respiration rate, and weight loss. Film-forming properties of the biopolymers permit formation of protective coating on the surface of perishable food products.

## 3. Biopolymers as sustainable food packaging materials

Biopolymer-based films and coating have been developed as an alternate to plastic packaging materials, as the latter is a petroleum-based non-biodegradable material that can result in serious problems for human health and environmental.[16] For preparing such packaging materials, various biopolymers namely polysaccharides (cellulose, starch, chitosan, etc.), proteins (corn zein, whey proteins, collagen, etc.), lipids (carnauba wax, shellac wax, etc.) or their combinations have been used as films and coating materials.[1,17] The interest in the development of biopolymer films and coating has increased during the last decade, as the raw materials used are environmental-friendly, abundantly available, and biodegradable (Kumar et al., 2020). Edible films are applied as thin film that are preformed and then applied to food surfaces, whereas edible coatings are formed directly onto food surfaces usually by dipping in or by spraying the coating formulation, which can be consumed along with food. A semi-permeable barrier is created by these films and coatings that restrict oxygen, carbon dioxide, moisture and solute movement, and thus reduce rate of respiration, loss of water and oxidation. Moreover, they enhance visual appeal by reducing physical damage, scars, and by improvement in surface shine.[18] Biopolymer can reduce 30–80% of emission of greenhouse gases, and offer higher postharvest shelf-life to the packaged food than the synthetic plastic packaging. Also, they can be used as compost in soil after their use and disposal. Despite these advantages, biopolymer-based films and coatings suffers from certain shortcoming like poor mechanical, barrier, and thermal properties.[16,19] Advancement in nanotechnology and use of plant-based active compounds in biopolymer-based films and coatings can mitigate these challenges. Incorporation of nanomaterials and/or plant-based natural active compounds in biopolymer improve thermal properties, gas and moisture barrier properties, mechanical strength and antimicrobial activity.[20]

### 3.1 Carbohydrate-based films and coatings

Carbohydrates have been widely explored for fabricating active films and coatings. Cellulose and their derivatives, chitosan, starch, pectin, and galactomannans has been enormously used for active antimicrobial food packaging applications.[16] Cellulose is the abundantly available natural organic polymer on the planet, which is composed of D-glucose units joined by β-1,4 glycoside bonds. Cellulose and its derivatives are the most important raw materials for preparation of edible films and coatings as they are biodegradable, odorless, tasteless, and have excellent film forming properties. The modified forms of cellulose that are commonly used in edible films and coatings include carboxymethyl cellulose (CMC), methylcellulose (MC), and hydroxypropyl methylcellulose (HPMC).[21] Edible coatings made of HPMC, CMC, HPC and MC have been extensively used for coating of fruits and vegetables that providing barrier against oxygen and moisture, and thus extending their postharvest shelf-life. Cereals, potato and other tubers, and legumes are the main natural resources of starch that consists two kinds of glucose polymers; amylose and amylopectin. Amylose are considered as good starch derivatives for film and coating material, as high amylose starch has high stability during prolong storage. For instance, corn starch is excellent source for coating and film fabrication, as it is tasteless, odorless, colorless and non-toxic having physical characteristics that resemble to synthetic plastic-based films and wax-coatings.[22] In addition, starch is cost-effective, abundant, biodegradable and convenient to fabricate edible coatings and films. Starch-based films suffer from relatively poor gas barrier properties that may be enhances by using nano-fillers, and or natural active phytochemicals.[23] Starch coated strawberries preserved the quality in terms of colour, weight loss and firmness, whereas, starch coated apples imparted high gloss at the beginning of storage. Cassava and rice starch-based coating applied on pummelo (Citrus Maxima Merr.) had reduced weight loss compared to uncoated pummelo.[24]

Chitosan, a deacetylation derivative of chitin, is a linear amino polysaccharide of D-glucosamine and N-acetyl-D-glucosamine units. Chitosan has been used in several fields including food and agriculture sector owing to its excellent antimicrobial and antioxidant activity, biodegradability, non-toxicity, biocompatibility, film forming capability, etc. Chitosan also has excellent mechanical and barrier properties against $O_2$ and $CO_2$ permeation. Chitosan based coatings improve postharvest longevity of fresh produce giving them smooth, shiny, cohesive and intact surface.[25] Chitosan films and coatings has been successfully used to maintain quality of several fruits such as strawberries, grapes, raspberries, sliced mango fruits, citrus fruits, fresh-cut water, etc.[26] Chitosan film can be produced by solution casting method, and it is blended with other polymers such starch, gelatin, CMC, alginate, etc. to improve their physico-chemical, mechanical, thermal, and barrier properties.[27] Alginate is a sodium salt of the alginic acid obtained from brown seaweed, and it possesses a strong film forming properties with translucent and glossy look. It is a linear copolymer of D-mannuronic acid and L-guluronic acid monomers. Due to its hydrophilic nature, alginate exhibit poor water resistance, which can be improved by adding calcium that produce strong and insoluble alginate films.[8] By blending with starch, oligosaccharides, and simple sugars, properties of alginate films can be improved. There are various reports on the incorporation of antimicrobials and antioxidants in alginate films and their subsequent effect on the postharvest shelf-life extension of fresh produce.[28,29] Alginate coatings have been successfully used to increase the shelf life of fresh-cut-apples by minimizing weight loss and browning, and by preserving firmness during storage. It has also been reported that alginate coatings reduced water loss from fresh-cut papaya, pear and melon.

Gums, naturally occurring polysaccharides, have the capability to hydrate in water either by a gel or emulsion formation. Gums have been used as excellent vehicles for active substances, also control their rate of diffusion, and control rate of maturation of fruit and vegetable. Gum coatings provide a barrier to reduce respiration rate, weight loss and maintain the nutritional value. In order to improve their mechanical barrier, antioxidant and antimicrobial properties, plant extracts, essential oils, phenolic compounds, vitamins, and nanomaterials can be incorporated into gum coatings. Gums have been approved as GRAS by FAO, and their use is safe for environment and consumers.[30] Gum arabic based coating has been found to increase the shelf-life and postharvest quality of tomato, apple, persimmon, banana, blueberry fruits.[31-34] Coating of these fruits showed reduced weight loss, decay percentage, and maintained firmness, titratable acidity, soluble solids concentration, ascorbic acid content, and color development, and delayed ripening process compared to uncoated fruits, and thus improved their postharvest shelf-life. Pectin is another plant derived polysaccharide that has poor moisture barrier that may be used for low moisture produce.[35] Oms-Oliu et al., 2008 developed a multi-layered coating formulation using pectin and other materials to extend the shelf-life of fresh-cut cantaloupe.[36] In this study, pectin-based coatings containing N-acetylcysteine and glutathione applied on of fresh-cut pears showed inhibition of microbial spoilage and maintenance of sensory attributes of pear wedges for 14 days. Pectin-based emulsions coating added with beeswax, sorbitol, and monoglyceride delayed spoilage and enhanced postharvest shelf life of cucumber for up to 2 weeks by retaining different quality parameters such as firmness, colour, amount of chlorophyll, etc.[37]

### 3.2 Protein-based films and coatings

Proteins are polymer of amino acids linked by peptide bonds that are amphiphilic, and have electrostatic charges with unique conformational structure. Protein-based films and coatings are good oxygen barrier that can be applied on food surface as efficient semi-permeable membrane against permeation of respiratory gases that results in reduced rates of respiration and ethylene production, delayed ripening and senescence, and thus extend the shelf-life of fresh produce. Proteins such as gelatin, wheat gluten, soy protein, whey protein, zein, casein, and collagen are commonly used in food coatings. Proteins derived from plants such as soy protein isolate are suitable for coating fruits and vegetables, and such coatings incorporated with the essential oil components reduced weight loss, control moisture loss, delay dehydration and fruit shriveling in Persian lime (*Citrus latifolia* Tanaka).[38] Protein-based edible coatings have good barriers properties against $CO_2$ and $O_2$ permeation, however, they are hydrophilic in nature, and thus are poor barrier against water vapor.[39] Calcium caseinate and whey protein-based coatings on apple and potato slices reduced browning by acting as oxygen barriers, and reducing the gas transfer rates, the postharvest quality of coated apple and mango were also improved.[40] Sodium caseinate-based films containing beeswax, oleic acid, and glycerol showed better gloss, transparency and surface roughness.[41]

| **Table 1.** Biopolymer-based active films for shelf-life extension of fruits and vegetables | | | | |
|---|---|---|---|---|
| **Fruits and vegetables** | **Composition of active films** | **Application techniques and storage condition** | **Effects on fruits and vegetables** | **Ref.** |
| Grapes (*Vitis vinifera*) | Agar (2.5%, w/v), ZnO (2-4% w/w) | Wrapped in composite films; Stored in ambient conditions for 25 days | Postharvest-life extension up to 21 days | 4 |
| Strawberries (*Fragaria ananassa*) | CMC (1% w/v), Guar gum (1% w/v), $AgNO_3$ (20 mL of 0.1 N) | Packaged in the developed films; at room temperature storage | CG-Ag°NC film enhanced shelf-life and decreased weight loss | 49 |
| Strawberries (*Fragaria ananassa*) | Chitosan (2% w/v), Essential oils (10% w/v) AgNPs (5% w/v) | Packaged in a PET clamshell box having 2 films at lower and 2 films at upper surface of the fruits, and stored for 12 days of storage at 4°C. | The developed active films showed reduced weight loss and decay during 12 days of storage, compared to control samples | 50 |
| Fresh-cut apples | Chitosan (2% w/v), Gelatin (2% w/v), Tannic acid (0-2 wt.%) | Cut-fruits are placed in a PET box, and then sealed by developed films | Film significantly reduced weight loss, delayed degree of browning, lipid oxidase activity and malondialdehyde content during 10 days storage at 4°C | 51 |
| White button mushroom, (*Agaricus bisporus*) | Bacterial cellulose (BC), Pomegranate peel extract (PPE) (25-50wt.%), Green tea extract (GTE) (25-50 wt.%), Rosemary extract (RE) (25-50wt. %) | Wrapped on active membranes mounted trays; at 4 - 8°C for 15 days | Remained good quality and marketable after 15 days of storage | 52 |
| Cherry tomato *(Lycopersicon esculentum Cerasiforme)* | Pectin (1% w/v), Glycerol (2.5% v/v), Magnesium hydroxide (1% w/w) | Packaged and stored at 30.2°C, 61.2% RH and at 10°C, 90% RH) | Extended the shelf life till 24 days in 10°C storage | 53 |
| Grape *(Vitus vinifera)* | Sodium alginate (2%, w/v), Gum acacia (2%, w/v), Basil leaves extract (1%, w/v), $AgNO_3$ (2%, w/v) | Packed and stored for 18 days | Reduced weight loss, retained shape, showed antimicrobial against foodborne pathogen; extended storage life | 54 |
| Apple (*Malus*) | Acylated soy protein (5–8%, w/v) Chitosan (0.29–0.46%, w/v) | Stored at room temperature | Film containing 6% soy protein, 0.34% chitosan and 0.26% stearic acid extended shelf life by a week | 55 |
| Cherry tomatoes (*Solanum Lycopersicum* L.) | Chitosan (2 %, w/v), and $TiO_2$ nanoparticles (1%, w/w) | Packed in the nanocomposite film; stored at 20°C, 85 % RH | Delayed ripening process and better quality maintenance | 56 |
| Green chillies (*Capsicum annuum*) | Chitosan (2%, w/v), Acetic acid (1%, v/v), Glycerol (0.5%, w/w), Citric acid (2%, w/w) | Packed in the film pouches; stored at 27°C for 7 days | Modified chitosan pouches showed higher moisture barrier, slower ripening | 48 |
| Black grape (*Vitis vinifera*) | Chitosan and cellulose acetate phthalate varying ratio, and ZnONPs (2.0–7.5%, w/w) | Wrapped in the nano composite films; Stored at ambient conditions for 9 days | The film with 5% ZnONPs extended shelf life up to 9 days | 57 |
| Okra (*Abelmoschus esculentus*) | Chitosan (2 %, w/v), and Zinc Oxide (0.1%, w/v) | Packed in and stored at room temperature | Maintained quality, retarded microbial growth for up to 12 days | 58 |
| Mushroom (*Agaricus bisporus*) | Chitosan (2%, w/v), Zein (2%, w/v) α-tocopherol (50%, w/w) | Packed and stored at 4°C for 12 days | Improved firmness, TPC, and antioxidant activity | 59 |

### 3.3 Lipid-based films and coatings

Edible lipids are traditional coating materials that provide better moisture barrier, and improve visual appearance of fresh fruits and vegetables. Lipids are hydrophobic in nature, and this lipid-based coatings possess good moisture barrier properties.[42,43] Carnauba wax, candelilla and beeswax are natural waxes extensively used in several edible films and coatings applications. For examples, to improve postharvest shelf-life of apples, oranges and mandarins, beeswax-based coatings have been applied.[44] Hybrid films and coatings combining lipid, polysaccharide, protein have also been studied for improvement in their barrier properties.[45]

## 4. Applications of biopolymer-based films and coatings

### 4.1 Films for packaging of fruits and vegetable

Biopolymers such as polysaccharide, protein, lipid and their derivatives have been used for fabrication of composite, nanocomposite of hybrid food packaging films with improved mechanical, barrier, thermal, antimicrobial and optical properties. These films have shown to effectively maintain quality of fresh produce including fruits and vegetables, and enhanced their postharvest shelf-life.[28] Biopolymer based composite films are prepared by solution-casting, layer-by-layer, and extrusion techniques, among which the solution casting method is commonly used for laboratory or small scale due to its convenience and simplicity (Figure 1).[4] In a study, biodegradable film placed on the surface of sliced and shredded carrots effectively delayed weight loss and prevented whitening of carrot during postharvest storage.[46] Chitosan-based film used for mango fruits showed better storage characteristic and extended their shelf-life up to 18 days and without any microbial growth and off-flavor.[47] Chitosan-based films containing citric acid as cross-linker, and glycerol as plasticizer were prepared using solvent casting method, and the developed films showed better water resistance, transparency, flexibility, thermal stability and antioxidant properties.[48] Several other studies reported that such biopolymer-based composite films are commonly used to make active pouch/package to prolong postharvest shelf-life and maintained quality of fruits and vegetables, as summarized in **Table-1**.

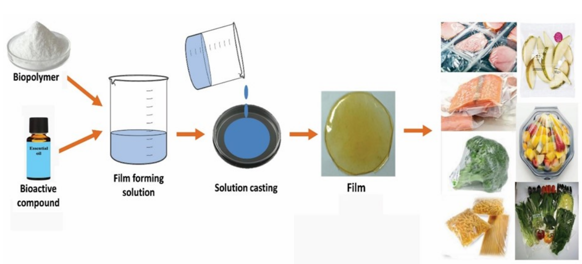



**Figure 1.** Fabrication of active films and their application

### 4.2 Coatings for shelf-life extension of fruits and vegetables

Coating is a thin layer of edible materials used on food surface for reducing moisture loss, gas exchange, and to maintain food quality by preserving their color, aroma, appearance, taste and texture that lead to extended postharvest shelf-life.[16,42] It acts as the protective barrier against microbial spoilage and slows down various metabolic activities such as respiration, oxidation, ripening, water loss, etc. Dipping, spraying and brushing are commonly used techniques for coating of fruits and vegetables (Figure 2). Along with other biopolymers, plant-based waxes have also been used as natural edible food coating materials primarily for coating of fresh fruits and vegetables.[60] For instances, tomato coated with gum arabic and almond gum showed a significant delay in weight loss, and maintained firmness, titratable acidity, soluble solids concentration, ascorbic acid content, percentage decay and color compared to the uncoated control fruit.[34,61] Chitosan-based coating showed effect on fruit ripening behavior, and biochemical and organoleptic characteristics of mango (*Mangifera indica* L.) during storage, it was evident that the coating have potential to maintain quality and extend shelf-life of mango.[62] Coating formulations containing pectin, beeswax, sorbitol, water, and an emulsifying agent have been used to preserve the fruit quality and extend the shelf life of cucumber, and the coating helped in reducing weight loss, respiration rate, and maintaining firmness, color, amount of chlorophyll and total soluble solids of the fruits.[37] In a similar study, gum arabic coated cucumber showed reduced weight loss, delayed softening, maintained firmness, and sensory characteristics of coated cucumbers.[63] Numerous biopolymer-based coatings containing active agents of plant and animal origin, and/or nanomaterials have been explored and found effective in extending postharvest shelf-life of fresh produce (**Table-2**).

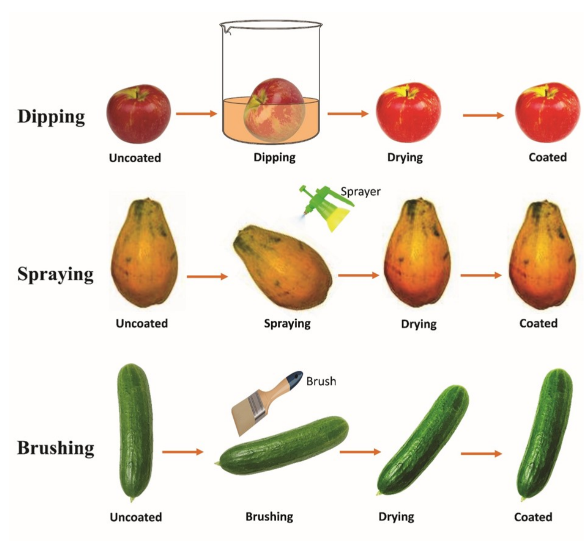



**Figure 2.** Various techniques of coating of fruits and vegetables

**Table 2.** Biopolymer-based active coatings for shelf-life extension of fruits and vegetables

| Fruits and vegetables | Composition of coating formulation | Coating techniques | Storage condition of coated fruits and vegetables | Effects of coatings on food products | Ref. |
|---|---|---|---|---|---|
| Kiwifruit (*Actinidia deliciosa*) | Hydroxypropyl methylcellulose (HPMC) (0.1wt.%) | Spraying by airbrush powered by $N_2$ and dried for 30 min | Packed in PET trays, 4°C, 90% RH; stored in dark for 12 days | Maintained TSS, firmness, brightness, greenness, and reduced browning, weight loss, and TSS/TA ratio | 64 |
| Cavendish banana *(Musa acuminata)* | Rice starch (3%, w/w), Κ-carrageenan (1.5%, w/w), and fatty acid ester of sucrose (FAEs) (2%, w/w) | Spraying for 10 s | 20°C, 52% RH | Decreased weight loss and starch degradation, maintained firmness and quality | 23 |
| Apples *(Malus)* | Chitosan (0.75%, w/v) | Dipping for 30 min | Packed in polypropylene with passive MAP at 1±2°C for 3 days | Reduced polyphenoloxidase (PPO) activity and microbial load | 65 |
| Fresh-cut guava *(Psidium guajava* L.) | Chitosan (1%, w/v) | Immersed in for 10 s and dried for 1 h at 24°C. | Packed in Styrofoam trays, and stored at 4ºC for 14 days, or at 24 °C for 7 days | Maintained quality including sensory attributes during storage | 66 |
| Avocado *(Persea americana* Mill. cv. Hass*)* | Sodium alginate (1.5%, w/v), | Dipped for 1 min | Stored at 6°C or 25°C for 15 days | Reduced weight loss by 2–3.7 %, controlled postharvest diseases in the fruit | 67 |
| Peaches *(Prunus persica)* | Sodium alginate (1%, w/v). | Dipping for 2 min | Stored at 28°C, 90% RH for 7 days | Reduced weight loss, respiration rate, maleic dialdehyde (MDA) content, polyphenol oxidase (PPO) activity, loss of firmness and TSS content | 68 |
| Tomato *(solanum lycopersicum),* Chilly *(Capsicum frutescens)* and Brinjal *(Solanum melongena)* | Chitosan nanoparticles (1%, 2%, 3%, 4%, 5%) | Dipping method | Stored at room temperature for 5 days | Decreased weight loss, cytotoxicity; effective antifungal, antioxidant coating | 69 |
| Blueberry *(Vaccinium sect. Cyanococcus)* | Chitosan (1%, w/v), Tween 20 (0.20 %, w/w) | Dipping method | Placed on PET trays, wrapped in PLA bags, and kept at 4°C for 14 days | Maintained firmness and increased antioxidant activity, and maintained overall quality during storage | 70 |
| Guavas *(Psidium guajava* L.) | Sodium alginate (5% m/v), Chitosan (5% m/v), acetic acid (0.5% v/v), glycerol (2% v/v), nanoZnO (1%, v/gel) | Dipped in coating formulation for 3 min | 21°C and 80% RH for 20 days | Delayed ripening, reduced weight loss, and improved shelf life | 71 |
| Blueberries (*Vaccinium corymbosum* L.) | Chitosan (2%, w/v), Sodium alginate (2%, w/v) | Dipped into the chilled (5°C) formulation for 2 min | Placed in polypropylene containers, and stored at 5°C | Controlled microbial growth, delayed spoilage, improved antioxidant properties and visual appearance, and maintained firmness | 72 |
| Sweet cherry (*Prunus avium* L.) | Guar gum (0.15%, w/v), Calcium chloride (0.1%, w/v), Ginseng extract (1%, w/v) | Dipped in the coating solution for 1 min | Stored in gauze bag at 20°C and 70-75% RH for 8 days | Reduced loss of water, maintained firmness, TA, AsA, and extended shelf life to 8 days | 73 |
| Sweet cherries (*Prunus avium* L.) | Carboxymethyl chitosan (2%, w/v), Gelatin (2%, w/v), CaCl2 powder (2%, w/v), L-ascorbic acid (2%, w/v), and Tween 20 (0.1 %, w/v) | Immersed in edible coating solution for 2 min | Packed into PET plastic boxes and stored at 0°C, RH 85–90 % for 30 days | Improved quality and antioxidant properties, reduced decay, weight loss, respiration rate, and pedicel browning, maintained TSS, titratable acidity and firmness | 74 |
| Apples (*Malus*) | Chitosan (2%, w/v), Sodium caseinate (4%, w/v) | Immersed in the coating for 1 min | Stored at 5°C or 10°C | Reduced respiration rate, preserved mechanical properties, antioxidant activity, improved shelf life by 4 days, when stored at 5°C | 75 |
| Strawberries (*Fragaria ananassa*) | Carrageenan (0.5%, w/v), Lemon grass essential oil (1%, w/v) | Immersed into coating solutions about 2 min | Packed in PE pouches, stored at 4°C for 12 days | Reduced weight loss, decay percentage, retained ascorbic acid, antioxidant activity and firmness | 76 |
| Strawberries (*Fragaria ananassa*) | Hydroxyethyl cellulose (1.0%, w/v) Sodium alginate (0.5%, w/v) Asparagus waste extract (10%, w/v) | Coating is done by dipping for 1 min and then air-drying for 1 h | Incubated at 25°C for 8 days at 80% RH | Coating maintained quality and extend the shelf life of the strawberry fruit | 77 |

## 5. Conclusion and perspectives

Plant-derived biopolymers such as starch, cellulose, agar, carnauba; those that are animal derived e.g., gelatin, casein, whey protein, beeswax; and microbial biopolymers such as dextran, xanthan, pullulan, bacterial cellulose and polylactic acids have been extensively studied and applied as biodegradable alternatives to synthetic plastic packaging films and coatings. Several studies have reported that blending of biopolymers and/or their reinforcement with nanomaterials such as cellulose nano fiber, montmorillonite nanoparticles, zinc oxide nanoparticles, silver nanoparticles, etc. not only significantly improved physicochemical, mechanical and barrier properties, but also enriched these biopolymer-based food packaging films and coatings with functionalities such as antimicrobial and antioxidant activities. Numerous studies have also reported that applications of these biodegradable, active composite packaging films and coatings on fresh fruits and vegetables resulted in significant improvement in postharvest shelf life. However, further research and development efforts are needed to popularize commercial manufacturing of these biodegradable composite films and coatings, and their applications in large scale food processing scenarios. Thus, biopolymer-based films and coatings are emerging as sustainable food packaging materials for prolonging postharvest shelf-life of fruits and vegetables.

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