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REVIEW PAPER

Bioactive properties and potential applications of Aloe vera gel edible coating on fresh and minimally processed fruits and vegetables: a review

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Abstract
Aloe vera gel provides numerous health benefits and is considered as one of the best coating materials, which is edible, safe, and biodegradable. It facilitates a barrier against moisture and gas exchange, conserves the firmness, color, and flavor of the fruits and vegetables. Besides, owing to the antimicrobial and antioxidative properties, Aloe vera coating provides reduced microbial proliferation and improved antioxidant activity of the stored produce. Hence, Aloe vera coating has been used as a noble edible coating for fresh produce. This review aims to highlight the application of Aloe vera gel coating alone or together with other functional compounds in order to extend postharvest shelf life and preservation quality of fresh and minimally processed fruits and vegetables. This study also summarizes relevant biological activities and compositional characteristics of the gel. Some challenges and future aspects of the application of Aloe vera coating have discussed as there is a growing interest in this unique edible coating. This information will help the food processors to identify the most effective Aloe vera coating concentration alone or in combination with other functional ingredients for a variety of fresh and minimally processed fruits and vegetables.

Keywords Aloe vera gel · Edible coating · Bioactive properties · Postharvest · Shelf life · Quality · Antimicrobial and antioxidative properties

Introduction

Fruits and vegetables are highly susceptible to spoilage after harvest. Being living entities, fruits, and vegetables continue to respire, i.e., use oxygen, and produce carbon dioxide. Due to continuous respiration, the metabolism process of carbohydrates, proteins, fats, and organic acids continues even after harvest. As a result, quality from every aspect, such as nutritional, physical, and chemical quality deteriorates [1]. Moreover, postharvest water loss affects the quality of fruits and vegetables and is a significant contributor to degradation. Wilting, shriveling, overripeness, chilling injury, and loss of texture are some signs of postharvest decay, which are resulted from excessive water loss [2, 3]. After harvest, the ripening and aging process of fruits and vegetables differs depending on whether they are climacteric or non-climacteric. After being detached from the plant at a certain maturity level, climacteric fruit can continue to attain the full physiological maturity during storage. Therefore, climacteric fruits can attain the maximum eating quality after harvest [4]. Climacteric fruits self-generate ethylene, which facilitates the ripening process and associated biochemical and enzymatic reactions [5]. Ethylene production further triggers the respiration rate and reduces the shelf life of climacteric fruits [2]. On the other hand, non-climacteric fruits cannot continue to reach the maximum eating quality or ripen after harvest; they only deteriorate due to aging and water loss and are insensitive to ethylene [4]. Overall, fruits and vegetables have very limited postharvest life that causes severe economic losses [6].

Various methods have been employed to extend the shelf life of fresh fruits and vegetables. Modified atmosphere packaging (MAP) [7, 8], controlled atmosphere storage

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(CA) [9, 10], shrink wrap packaging [8], surface coatings [11, 12], vacuum packaging [13], UV-C irradiation and low temperature storage [14], and treatments with chemical compounds such as 1-MCP, nitric oxide, salicylic acid, and chlorine dioxide [15, 16] are some of the strategies found to be suitable in extending the shelf life of fresh produce. Among the methods investigated, edible coatings are being considered as one of the most innovative techniques in fruits and vegetable packaging. Edible coatings are applied as a thin layer of material to provide a barrier against a variety of factors that would otherwise deteriorate the postharvest quality. Due to the concern about the disposal of synthetic materials, naturally occurring packaging materials have been drawing increased attention [17, 18]. Like a suitable conventional packaging, bio-based packaging acts as a moisture barrier to prevent moisture loss from the fresh produce, acts as a barrier against the exchange of gas and volatile compounds, and gives protection from physical damage with a low-cost investment [19]. Moreover, it carries critical functional ingredients, such as antioxidants and antimicrobial compounds [20]. Edible coatings/films can be natural substances, for example, proteins, polysaccharides, and lipids. Different types of polysaccharides such as chitosan, pectin, alginate, various gums, and Aloe vera gel have been extensively used to coat fresh fruits and vegetables.

Polysaccharide based edible coatings maintain the postharvest quality of fruits and vegetables and are environmentally friendly [21]. Aloe vera gel coating is a non-toxic and eco-friendly natural edible coating [22]. Quite a few studies have been conducted to explore its potential as a postharvest treatment for fruits and vegetables. Aloe vera gel alone or in combination with other functional ingredients has been found beneficial in retaining the postharvest quality of a variety of fresh fruits and vegetables by reducing the respiration and transpiration process by providing a barrier to atmospheric gases and moisture [18] (Fig. 1). Besides,

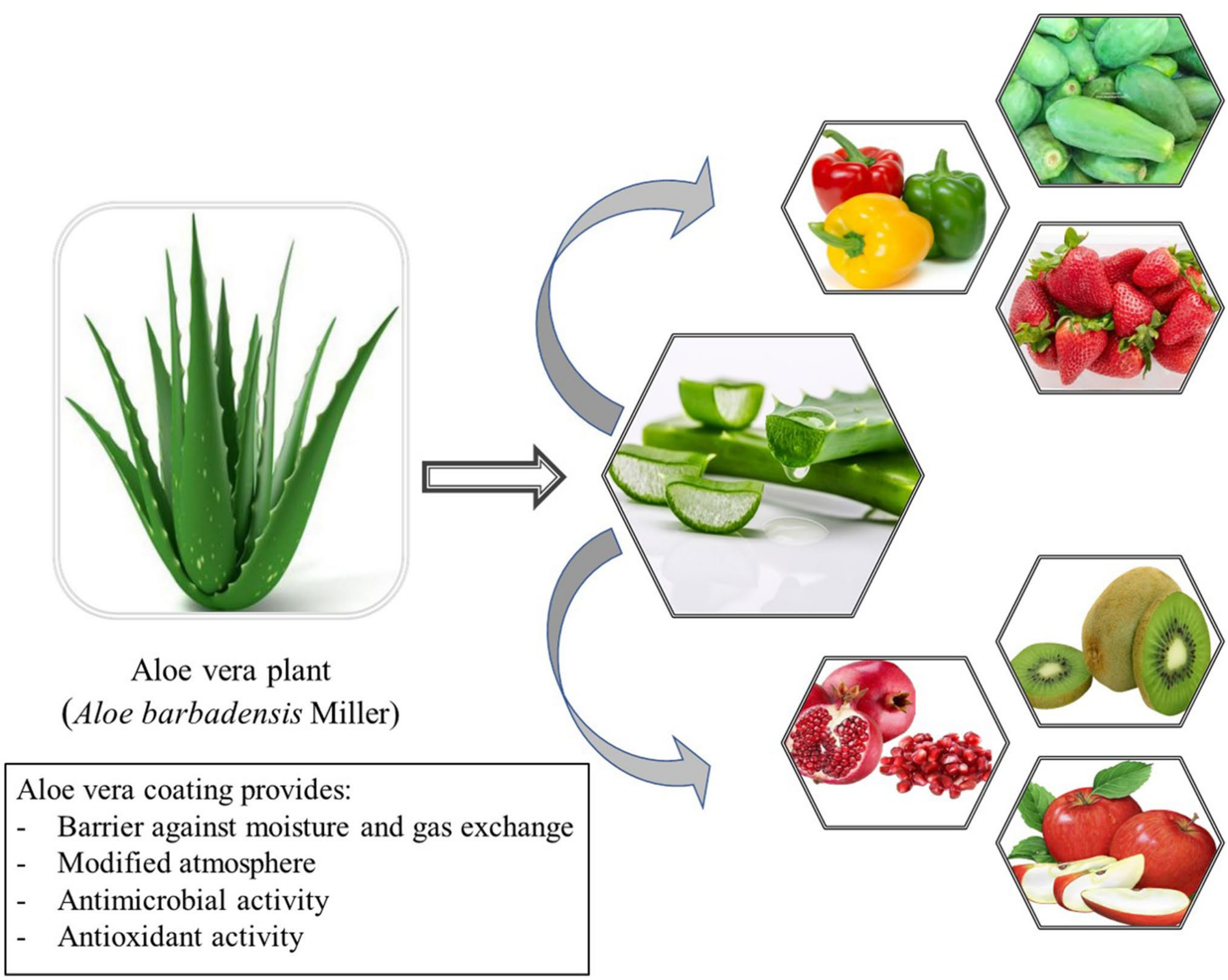

Fig. 1 Potential benefits of Aloe vera gel coating on fresh and minimally processed fruits and vegetables

Aloe vera coating conserves the overall visual quality and inhibits the microbial growth and oxidation processes [22]. Similarly, Aloe vera coating has been used in the shelf life extension of minimally processed fruits and vegetables by reducing the deleterious effects of minimal processing and restricting the microbial proliferation [23–25] (Fig. 1). However, processing the Aloe gel to be used as an edible coating or in any other food application might risk the loss of the bioactive components in the gel. Further, identifying an ideal concentration of the Aloe gel or another functional ingredient to be incorporated into the coating matrix to ensure the most efficient postharvest quality of a specific commodity might be a little challenging.

Several reviews based on Aloe vera gel coatings on fresh fruits have been reported in the literature; those studies highlighted the effect of coating on the physico-chemical properties of fruits [26], studied the role of Aloe vera coating on the shelf life of few fruits [27] or discussed the food preservative characteristics of Aloe vera coatings in terms of their effects on external, internal and hidden food quality attributes [18]. However, this study aims to review various recent applications of Aloe gel coating alone or as a combination with other edible and functional ingredients on fresh and minimally processed fruits and vegetables. Relevant information about the compositional characteristics, biological activities, and film-forming properties, as well as the limitations associated with the applications of Aloe vera gel coatings were also discussed.

Desirable properties of edible coating applied on fruits and vegetables

An edible coating, as the name suggests, can be consumed with the food it contains and is able to biodegrade. Edible coatings are one type of edible packages that are applied once in a liquid state and as a thin layer on fruits and vegetables [28]. Edible coatings on fruits and vegetables have been considered as viable, environmentally-friendly alternatives to their synthetic counterparts due to their ability to serve as semipermeable barriers to moisture, vapor, gases, and solute [6, 28]. The limited movement of gases like oxygen and carbon dioxide and water vapor leads to reduced respiration rate and weight loss of the fresh produce. Those attributes of an edible coating resulted in firmer produce with a longer shelf life. Besides working as a barrier, edible coatings provide antimicrobial, antioxidant, and antibrowning activities [1, 2]. Phenolic compounds contributing to the antioxidant capacity of fruits and vegetables begin to decrease due to the increased activities of phenol oxidase and peroxidase as the fruit start to senescence [16, 29]. Edible coatings limit the enzymatic activities, reduce the polyphenol losses, and conserves the antioxidant capacity and nutritional value of fruits [2]. Besides biochemical and physiological changes, postharvest quality of fruits and vegetables deteriorates due to microbial proliferation and contamination. Various coating materials have been reported to exhibit natural antimicrobial properties, and many studies demonstrated the effectiveness of edible coatings in reducing the decay incidence in fresh produce [25, 30, 31]. As a consequence, the incorporation of antimicrobial compounds in the form of edible coating contributes to the increased interest in this field [6]. Moreover, since edible coatings suppress respiration rate, it ultimately delays the color changes of fruits and vegetables by limiting the enzymatic activities responsible for anthocyanin and carotenoid synthesis [2, 15]. Therefore, the application of edible coatings has become an effective method in extending the shelf life of fruits and vegetables while maintaining safety and quality during storage.

General information of different edible coating applied on fruits and vegetables

Various proteins, polysaccharides, and lipids have been used as basic ingredients of edible coatings. Further, a combination of two or more basic ingredients, as well as the addition of other ingredients with bioactive properties, have been reported to be very promising postharvest strategies [30]. A range of naturally occurring polysaccharides such as gums [21], chitosan [15], hydroxypropylmethyl cellulose [32], Aloe vera [25], alginate, starch, and pectin [33] has been reported to be effective in extending the shelf life of fresh horticultural produce. Soybean protein isolate, zein, wheat gluten, milk, and egg proteins [30, 33] are some examples of proteins used as edible coatings for fruits and vegetables. On the other hand, different types of waxes such as carnauba wax, beeswax, and candelilla wax [33, 34] are some of the widely used lipid-based edible coatings. Moreover, composite coatings made from two or more basic compounds with improved functionalities have been gaining increased interest in edible coating research. Some of the examples of composite coatings effectively applied on fresh fruits include soybean protein isolate-chitosan [30], rice starch-carrageenan [16], pea starch-guar gum [35], and banana starch-chitosan-Aloe vera [11], etc. Recently, nanotechnology has been used as an innovative and effective technique applied to improve the performance of edible coatings. Nanochitosan was reported to possess stronger antimicrobial activity than that of the coarse chitosan solutions [36], and due to the stronger activity, a smaller dose of nanomaterials might be useful as an edible antimicrobial coating.

Aloe vera

Aloe vera is a tropical and subtropical succulent cactus type plant that used to belong to the Liliaceae family but later was placed in the family Aloaceae [37]. It grows in warm and dry climates. Aloe vera leaves are composed of a thick epidermis or skin covered with cuticles that surrounds the mesophyll. The mesophylls are divided into two types of cells, such as chlorenchyma cells and thinner-walled cells forming the parenchyma. The parenchyma is called the filet. Aloe gel is a colorless mucilaginous gel that is isolated from the parenchymatous cells of the Aloe vera leaves. Aloe vera gel consists of water as high as 99.5% and 0.5–1.0% solid, which are simple and complex polysaccharides, vitamins, minerals, enzymes, phenolic compounds, and organic acids [38]. Out of over 250 species grown all over the world, only two species of Aloe vera, i.e., *Aloe barbadensis* Miller and *Aloe aborescens* have gained commercial importance [39]. Aloe vera (*A. barbadensis* Miller) has been considered a wonder plant due to its multidimensional health benefits [40] and has been utilized for centuries because of its unique medicinal and therapeutic properties [37, 41]. Besides, Aloe vera gel is getting increased interest in the food industry to be used as a source of functional foods in a variety of drinks, beverages, and ice creams [42]. The incorporation of Aloe vera gel enhances the nutritional and medicinal properties and improves the physicochemical properties of foods [37].

Aloe vera gel filleting process

Improper handling of the leaves leads to the gel quality degradation because of the enzymatic and microbial activities that occur after harvest. To preserve the functionality of the gel, the leaf should immediately go to the processing plant after harvest or should be kept in refrigerated storage within six h of harvesting [43]. Gel filleting can be done either manually or through a mechanical process. The primary purpose is to collect the internal fillet while removing the outer part of the leaf, i.e., rind, tips, bases, and thorns. Therefore, the Aloe vera fillets, which is 30–50% w/w of a leaf, and the rinds are the two products that resulted from the filleting process [44]. However, precautions should be taken during the filleting process so that the inner gel does not get contaminated with the yellow sap, which contains anthraquinones [44]; anthraquinones are responsible for the non-enzymatic browning of the Aloe gel [43]. In the manual filleting process, the leaf base, top, and thorns present along the leaf margins are removed, followed by removing the top and bottom rinds with a sharp knife [45]. Thus, the inner gel materials are collected while maintaining a lower level of anthraquinones. On the other hand, mechanical filleting is the most popular method used by industries, which involves a conveyor belt fitted with rollers and blades. In this process, the gel fillet is isolated through the blades' mechanical action in cutting away the lower and upper rinds. Then, the collected gel fillets are either chopped into pieces or liquidized and filtered to remove the fibers from the gel [43, 46]. Above all, it is crucial to complete the filleting operation within 36 h of harvesting the leaves to retain the biological activity of the gel [47].

Composition of Aloe vera gel

The gel consists primarily of saccharides, anthraquinones, glycoproteins, and various low–molecular-weight substances [48]. Cellulose, hemicellulose, and storage polysaccharides such as glucomannans, mannose derivatives, and acetylated compounds are the major polysaccharides in the Aloe gel [49], but the acetylated glucomannan molecules contribute to the thick, mucilage like properties of the fresh Aloe gel [48]. However, chemical compositions could vary among the species, and a lot of investigators aimed at the compositional analysis of the Aloe vera gel did not reveal the species examined [50]. In general, carbohydrates of the gel are made up of mono and polysaccharides such as glucomannans, xylose, mannose, cellulose, rhamnose, galactose, and arabinose [39, 51]. Polysaccharides being the major constituent of the gel, are mainly glucomannans, either acetylated or not. However, different polysaccharide structures have been reported, and this difference might be attributed to diversity in the geographical locations as well as the study with separate varieties of the Aloe plant. The polysaccharides are believed to be associated with many biological activities that include wound healing, antifungal activity, antidiabetic effects, anti-inflammatory, anticancer, immune-modulatory, and gastro-protective properties [52, 53]. Anthraquinones which are specific to Aloe gel are aloin, aloe-emodin, barbaloin, isobarbaloin, etc. Among the series of glycosides or anthraquinones present in Aloe gel, aloin A and aloin B is the most prominent. Also, aloesin, β-sitosterol, diethylhexylphthalate, vitamins, and beta-carotene are examples of low–molecular-weight substances present in Aloe vera gel [54]. The enzymes present in Aloe vera gel are catalase, amylase, oxidase, cellulase, peroxidase, lipase, alkaline phosphatase, cyclooxidase, cyclooxygenase, superoxide dismutase, and carboxypeptidase [51]. There is an ample amount of potassium and chloride in the Aloe gel but sodium, calcium, magnesium, copper, zinc, chromium, and iron are present in a small amount [37]. Moreover, Aloe gel contains seven essential amino acids out of 20 amino acids present in the gel [39]. Cholesterol, campesterol, lupeol, and beta-sitosterol are sterols present in the Aloe gel [55]. Besides, the vitamins in the Aloe gel include Vitamin A, C,

Table 1 Constituents of Aloe vera gel

Constituents	Examples	References
Carbohydrates	Cellulose, hemicellulose, storage polysaccharides (glucomannans, mannose derivatives, and acetylated compounds), xylose, rhamnose, galactose, and arabinose	[39, 48, 49]
Anthraquinones	Aloin, aloe-emodin, aloetic acid, anthranol barbaloin, isobarbaloin	[54]
Enzymes	Catalase, amylase, oxidase, cellulase, lipase carboxypeptidase, alkaline phosphatase, cyclooxidase, cyclooxygenase	[48, 56]
Low–molecular-weight substances	Cholesterol, gibberellin, lectin-like substance lignins, salicylic acid, β-sitosterol, steroids, triglycerides, uric acid	[54]
Minerals	Calcium, chlorine, chromium, copper, potassium, phosphorous, sodium, magnesium, zinc, iron	[37, 39]
Vitamins	A, C, E, B1, B 2, B 6, B 9 β-carotene, folic acid, choline	[37, 48]
Lipids	Cholesterol, campesterol, lupeol, beta sitosterol, triglicerides, triterpenoid	[48, 55]
Amino acids	Alanine, arginine, aspartic acid, glutamic acid, glycine, histidine, hydroxyproline, isoleucine, leucine, lysine, methionine, phenylalanine, proline, threonine, tyrosine, valine	[39, 48]

E, B1, B 2, B 6, B 9, and choline [37]. Examples of different Aloe vera gel constitutes are listed in Table 1.

Based on a recent study, overall, approximately 110 potentially active constituents isolated from the Aloe gel, which were categorized under six (6) classes [18]. The main classes are chromone and anthraquinone and their glycoside derivatives, while the other classes are flavonoids and their glycoside derivatives, phenylpropanoids, coumarins, phenylpyrone derivatives, phytosterols, naphthalene analogs, lipids, and vitamin, and others. The six classes of constituents isolated from Aloe vera gel are presented in Fig. 2. Furthermore, moisture content, ash, fiber, protein, lipids, minerals, organic acids, free sugars, and polysaccharides are among the other constituents obtained during the chemical analysis of Aloe vera gel [18].

Bioactive properties of Aloe gel

Biological activity or pharmacological activity can be defined by any beneficial or negative effect of a drug on the living substances. The whole Aloe gel extract has various biological properties [54]. Through various studies, it has

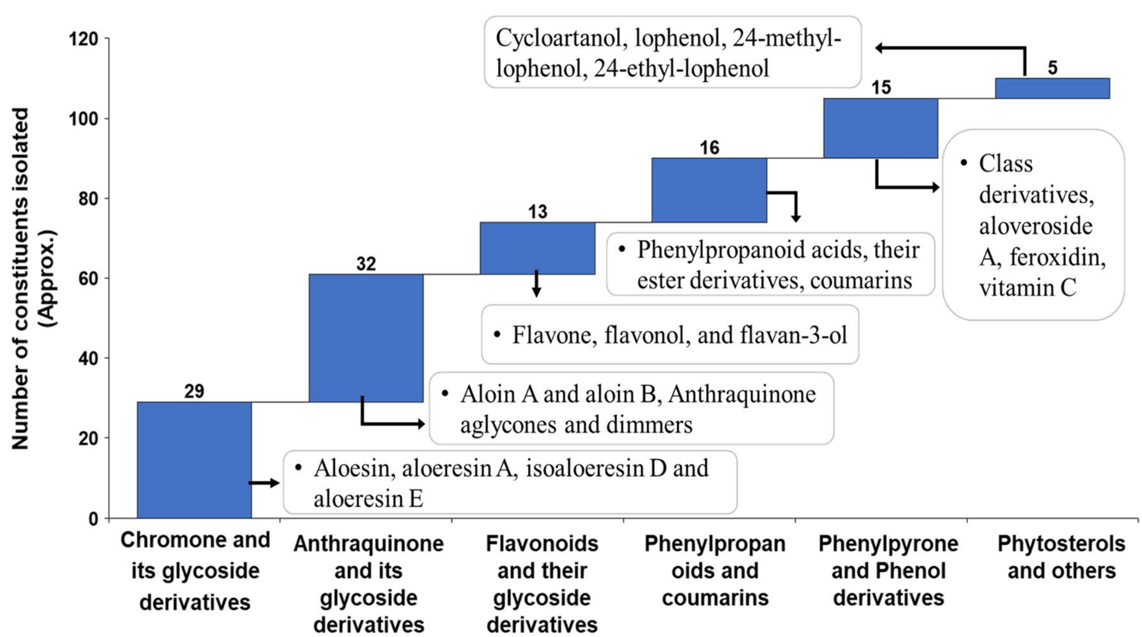

Fig. 2 Active constituents' classes of Aloe vera gel with the text boxes showing the major constituents in each class. Adapted from Kahramanoğlu et al. [18]

been reported that the Aloe vera gel has various biological activities, for example, immunomodulation, anti-inflammatory properties, wound healing, enhancement of radiation damage repair, various anti-microbial, antidiabetic, anticancer, and antioxidant activities [48]. However, anti-inflammatory and wound healing activities of the Aloe vera gel becomes the most reported topic in literature [54]. Subramanian et al. [57] examined the wound healing activities of Aloe vera gel in laboratory rabbits; the study suggests that the extract exhibits a positive influence on wound contraction and other biochemical properties in terms of wound healing. In the wound healing process, inflammation reduction is often termed as the first step of the process [54]. Aloin, aloesin, and Aloe gel was studied to examine the anti-inflammatory activity and was found to have that activity in a DSS (3% dextran sulfate sodium)-induced ulcerative rat colitis model [58]. Polysaccharides isolated from Aloe gel were shown to exhibit cell proliferation and wound healing activities [59, 60]. Aloe vera gel exerts wound healing activities by increasing the rate of wound contraction and collagen synthesis [53]. The connection between the Aloe vera components and their biological activities should be made, and thus researchers have been attempted to isolate an individual active ingredient to validate its effect on biological matters [54]. For example, glycoprotein fractions have been reported to have wound healing properties. An isolated glycoprotein fraction G1G1M1D12 of the Aloe vera gel was found effective on human foreskin keratinocytes and squamous cell carcinoma cells for the formation of epidermal tissue and consequently in wound healing with significant cell proliferation. Therefore, it is concluded that Aloe vera gel is effective for the wound-healing process through this glycoprotein fraction which is capable of cell proliferation activity [54]. Similarly, Xing et al. [61] reported that acemannan, a bioactive polysaccharide isolated from Aloe vera gel, facilitated skin would healing and cell proliferation through activating AKT/mTOR-mediated protein translation mechanism. Likewise, saccharide components of Aloe vera leaf gel have been reported to possess wound healing properties. Mannose-6-phosphate being the major sugar in Aloe vera gel, was examined for the wound healing activity, and it was reported that mice showed improved wound healing while receiving 300 mg/kg of mannose-6-phosphate [54]. Also, low molecular weight substances have wound healing properties. Lee et al. [62] conduct a study on the angiogenic activity of Aloe vera gel in chick embryo chorioallantoic membrane assay. Dichloromethane extract and methanol soluble fraction of Dichloromethane extract containing low molecular weight substances of Aloe vera gel were isolated. The application of methanol soluble fraction of Dichloromethane extract with low molecular weight substances exhibits more angiogenesis than the control counterpart. Further, a low molecular weight substance called β-sitosterol was isolated from Aloe vera gel to study its angiogenic activity on the damaged blood vessels of the Mongolian gerbil in a chick embryo chorioallantoic membrane assay. With this study, β-sitosterol was reported to exhibit an angiogenic effect on the specimen studied [63].

Plant materials exhibited various mode of action against microorganisms; they have the ability to reinforce the permeability through the phospholipoidal cell membranes which weakens the cellular integrity, reduce the cellular energy by inactivating respective enzymes, and deteriorate the genetic material inside the cell [64]. Similarly, Aloe vera leaf gel, which contains many antibiotics and antifungal substances, can retard or delay the growth of microorganisms [65]. The reason why Aloe vera gel is used in the edible coating mostly due to its antimicrobial activity and ease of preparation [66]. Aloe vera gel has been reported to have antifungal activity against several postharvest pathogenic fungi, including *Penicillium digitatum*, *Penicillium expansum*, *Botrytis cinerea, Alternaria alternata,* and *Aspergillus niger* [67–69]. It has been claimed that the gel has antibacterial activity against both Gram-positive and Gram-negative bacteria [70]. Activity against the bacteria *Shigella Flexneri*, *Streptococcus progenies* [71], and *Heliobacter pylori* [72] was reported. Antibacterial activity of the gel was attributed to the saponins, acemannan, and anthraquinone derivatives isolated from Aloe vera gel [73]. In the gel, a hydroxylated phenol called pyrocatechol was referred to possess a toxic effect on microorganisms [74, 75]. Antiviral and/or virucidal effects of the anthraquinones emodin and barbaloin were demonstrated on enveloped viruses [76]. Moreover, an isolated and purified Aloe protein of 14 kDa from the Aloe vera leaf gel was found effective against *Candida paraprilosis*, *Candida krusei*, and *Candida albicans* [77]. Polysaccharides present in Aloe vera gel inactivate bacteria through the stimulation of phagocytic leucocytes [78]. Aloe vera gel coating has been reported to inhibit or delay food spoilage by preventing the growth of microorganisms. The application of the Aloe vera coating on table grapes [73, 79], kiwifruit slices [23], sweet cherry [80], blueberry [81] and ready-to-eat pomegranate arils [82] was found effective in reducing the load of mesophilic aerobic bacteria, yeasts, and molds during storage. Therefore, the incorporation of antimicrobial compounds as a form of edible coating could inhibit the food surface contamination, and potentially reduce the direct application of antimicrobials in foods [83].

Plant extracts with antioxidative properties can be utilized in the food industry in order to reduce the oxidative process in food systems and the human body [64, 84]. The whole gel, as well as different fractions of Aloe vera gel, has been reported to exhibit antioxidant activity. Aloe vera gel is composed of various antioxidants such as α-tocopherol, carotenoids, ascorbic acid, flavonoids, tannins, and exhibits a dose-dependent antioxidant effect [48]. Moreover, Aloe-emodin, which is an anthraquinone derivative, was termed as one of the main components responsible for the antioxidant activity of the gel [85]. In vitro study of the radioprotective efficacy of Aloe vera gel revealed the ability of the gel to scavenge the free radicals 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2′-azinobis-(3-ethylbenzothiazoline-6- sulfonic acid), and nitric oxide [86]. In raspberry fruit, the application of Aloe vera coating improved the potential activities of several enzymes and non-enzyme antioxidant components, which resulted in an increment of the antioxidant capacity of the fruit [87]. On the other hand, Aloe vera gel, while applied as an edible coating, was found beneficial concerning the retention of the total antioxidant activity of table grapes [73]. Similarly, according to Rehman et al. [88], Aloe vera gel coating contributed to reduced lipid peroxidation of stored guava fruit by maintaining the antioxidative components such as polyphenol, flavonoid, ascorbic acid, and carotenoids. Moreover, coated guava fruits had higher enzymatic antioxidants and, therefore, exhibited reduced browning resulted from oxidative damage [88]. Due to an increased interest in bio-based antimicrobial and antioxidant packaging materials [83, 89], Aloe vera gel edible coating having bioactive properties can be a promising alternative to its synthetic counterparts to be used in the fresh produce industry.

Aloe vera gel film properties and interactions with other edible films

Aloe vera gel edible film primarily works as a barrier to preserve and protect the food from early deterioration. Water vapor permeability (WVP), water-solubility (WS), oxygen permeability, and mechanical strength are the critical factors determining the performance of edible films. Biopolymer based films are environmentally- friendly; however, they possess limited mechanical, thermal, and barrier properties to be served as ideal packaging materials [90, 91]. Aloe vera gel has not been widely used in edible films and coatings formulation due to its insufficient film-forming properties, although it possesses potent antimicrobial and antioxidant properties [92]. Therefore, Aloe vera gel film might provide low barrier properties and allow water permeability to some extent. As a result, other compounds with desirable film-forming properties such as starch, cellulose, gelatin, gellan gum, etc., have been added to the Aloe vera solution to improve the film characteristics [93, 94]. Mechanical strength or physical integrity of the film is vital to achieving an optimal barrier property [91]. However, Aloe vera film was reported to be soft and highly flexible. Therefore, attempts have been made to improve the film properties; Aloe vera (Al) solution was blended with gellan gum (Ge) and the resulting blend was reported to have enhanced nanomechanical properties due to the chemical and structural interactions between Al and Ge. Moreover, the AlGe blend had an improved water vapor impermeability than the Al alone [93]. Water vapor permeability of gelatin-Aloe vera composite film was reduced due to the addition of Aloe vera; the reduced WVP was attributed to the restricted movement of water molecules due to the cross-linkages between the polysaccharides in the Aloe gel and gelation leading to reduced free space in the composite film (Fig. 3). Besides, the incorporated Aloe gel contributed to the reduced water solubility but week mechanical strength to the gelatin film [95].

Plantain flour-glycerol-aloe vera composite film was reported to be water-insoluble and rigid with a higher concentration of Aloe gel because of the strong interaction and crosslinking of Aloe gel with the starch molecules and glycerol. On the other hand, the film with low Aloe content was

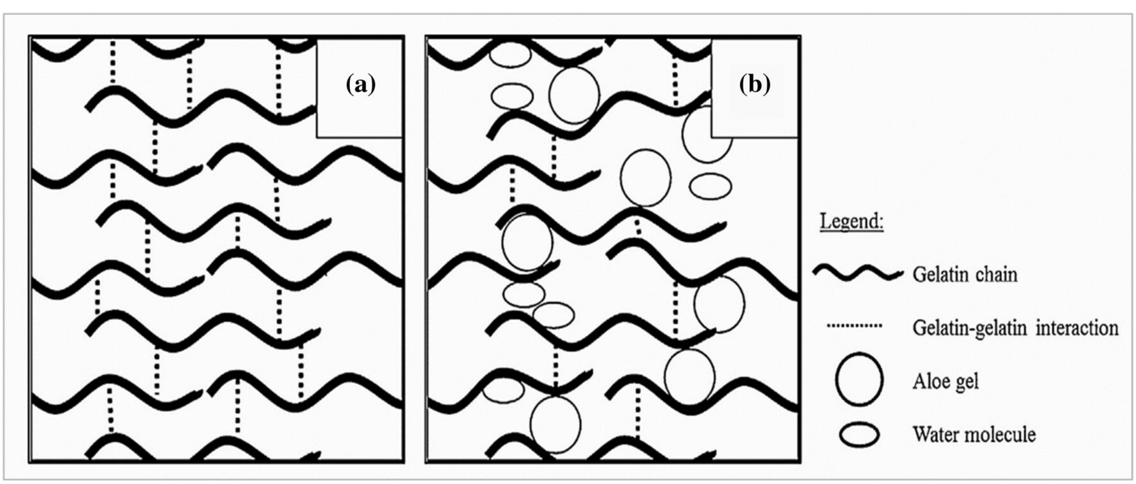

Fig. 3 Gelatin-gelatin interaction **a** without Aloe gel and **b** with Aloe gel. *Source:* Chin et al. [95]

found to be more water-soluble [96]. An edible film's WVP depends on the ratio of hydrophilic and non-hydrophilic groups in the film. Starch-chitosan-aloe vera gel film exhibited reduced WVP having a substantial Aloe gel concentration, given that the interaction of Aloe components with the chitosan molecules makes the hydrophilic group in chitosan unavailable to interact with water and, therefore, reduced the WVP of the film. On the contrary, WS of the film was found to be a function of Aloe vera concentration, which was attributed to the high WS of individual Aloe components such as sugars, organic acids, amino acids, etc. [92]. Similarly, the incorporation of Aloe vera gel in chitosan-based films was found promising since the addition of Aloe gel led to the improved mechanical properties and reduced WVP of the film. However, a threshold of 20% Aloe gel concentration was recommended [97]. Further, inclusions of nanoparticles to biodegradable films have been reported to be a promising strategy due to their ability to improve the critical properties such as barrier, mechanical, thermal, optical, and morphological characteristics of the films [91, 98, 99]. For example, Nieto-Suaza et al. [99] reported that incorporation of starch nanoparticles to Aloe vera gel-banana starch composite films not only reduced the WVP but also enhanced the mechanical properties of the films.

Potential applications of Aloe vera gel edible coating

Aloe vera gel (alone) coating application on fresh fruits and vegetables

Fresh fruits and vegetables are very susceptible to postharvest decay and spoilage owing to their high moisture content. Further, poor handling practices, inappropriate storage conditions, and ethylene exposure lead to enhanced deterioration of postharvest quality [100]. Various packaging techniques were found helpful in reducing the decay index and extending the shelf life of fresh produce. Among the different packaging methods, the edible coating is non-toxic and sustainable. Aloe vera is a novel edible coating material that provides a modified atmosphere, reduced moisture loss, respiration rates, and microorganism growth, and delayed oxidative browning in fruits and vegetables [25, 87]. The Aloe vera gel-coated papaya maintained its shelf life up to 12 days at room temperature and started decaying on the 16th day. The coated fruits also maintained their color, flavor and firmness up to 12 days of storage. An increase in ascorbic acid content and reduced disease incidence was also reported [101]. Ali et al. [102] studied different Aloe vera coating concentrations applied to grapes and stored in poly packaging and open plates in refrigerators and incubators. Among the tested concentrations, 20 percent was the most effective in extending the shelf life of grapes. Moreover, a combination of low-temperature storage, edible coating, and poly packaging helped to prolong the marketability by reducing moisture loss. Pineapple was coated with Aloe vera gel to store at an ambient temperature of 27 ± 2 °C and relative humidity of 55–60% for 7 weeks. The postharvest quality parameters were significantly retained in the pineapple coated with Aloe vera gel [103]. Nwosu and Ozumba [104] reported that Aloe vera coated cucumber stored at 34 °C was generally more acceptable than uncoated refrigerated ones at 4 °C during the storage period of 30 days. Table grapes (*Vitis vinifera* L. cv. Crimson Seedless) were coated with Aloe vera gel to study the effect of Aloe vera on the functional properties of grapes. Fruits coated with Aloe vera gel maintained the ascorbic acid content during cold storage at 1 °C for 35 days and shelf life at 20 °C, whereas uncoated clusters had undergone a rapid loss of functional compounds, such as total phenolics and ascorbic acid. Besides, there was a reduction of the total antioxidant activity and an increase in total anthocyanin, indicating an accelerated ripening process [73]. 'Arctic Snow' nectarine was coated with Aloe vera gel to evaluate the role of coating on ripening and fruit quality. The gel-coated fruits stored either at ambient or cold storage for 3 and 6 weeks maintained the postharvest quality through reduced respiration rate, ethylene production, fruit softening, electrolyte leakage, weight loss, levels of ascorbic acid, and total antioxidants during the ripening process compared to their control counterparts [105]. Martínez-Romero et al. [80] treated sweet cherry with Aloe vera gel diluted with distilled water (1:3). During cold storage at 1 °C and 95% RH, uncoated fruit had an increased respiration rate, rapid weight loss, and color changes, accelerated softening and ripening, stem browning, and increased microbial populations. But Aloe vera treated fruits notably delayed the above quality loss parameters, and sensory analysis showed favorable effects in terms of delaying stem browning and dehydration and retaining fruit appearance. Similarly, tomatoes were recommended to be treated with 10% Aloe vera coating during storage at 11 °C and 90% relative humidity to be able to maintain the postharvest quality [106]. A similar beneficial effect of Aloe vera coating was reported for Iranian sour cherries (Prunuscerasus); cherries were coated with fresh Aloe vera gel and packaged with packaging material made of polyethylene terephthalate and wrapped with low-density polyethylene before storing at 4 ± 1 °C for 17 days. The examination of physicochemical characteristics revealed that gel-coated samples were retained the postharvest quality parameters. Moreover, Aloe vera gel added a natural glow to the sour cherry fruit, which was pretty close to the fresh produce [42]. Similarly, Aloe vera gel coating has been reported as a promising bio-based coating for peach fruits as it promoted the postharvest traits of peach both qualitatively and quantitatively. Consequently, it was suggested to be a

Table 2 Examples of fruits and vegetables coated with Aloe vera gel as a single coating material

Fruits and vegetables (scientific name)	Tested concentrations	Test condition	Key variables studied	Results	References
Papaya (*Carica papaya*)	100%	12 days at room temperature (25–29 °C) and 82–84% RH	WL, TSS, TA, AA, F, C, Fl, PDI	The coated fruits maintained their color, flavor, and firmness up to 12 days of storage. There was an increase in ascorbic acid content and reduced disease incidence	[101]
Tomato (*Solanum lycopersicum* L.)	0, 5, 10, 15, and 20%	14 days at 11 °C and 90% RH	F, WL, C, SS, TA, AA, DS, RR, Et	Decreased ripening index and increased ascorbic acid with the conservation of overall quality in 10% Aloe- coated tomatoes	[106]
Grapes (*Vitis vinifera*. L.)	0, 10, 20, and 30%	Stored in poly packaging and open plates at 0 °C and 30 °C	pH, WL, C, DS, ST	20% Aloe vera coating was the most effective in extending the shelf life; it resulted in the best visual and physicochemical results	[102]
Table grapes (*Vitis vinifera*. L.)	Diluted 1:3 with distilled water	35 days at 1 °C and 95% RH; shelf life monitored at 20 °C, 90% RH for 4 days	TAA, PC, AA, TAC	Functional compounds, such as total phenolics and ascorbic acid, were maintained by the Aloe vera coating	[73]
-do-	Diluted 1:3 with distilled water	35 days at 1 °C and 95% RH; shelf life monitored at 20 °C, 90% RH for 4 days	WL, C, F, TSS, TA, ST, RR, MG, Et	Aloe vera gel delayed postharvest quality losses, extended storability from 7 to 35 days at 1 °C. Coating reduced MG	[79]
-do-	Diluted 1:3 with distilled water	0, 7, 21, 28, and 35 days at 2 °C	C, F, WL, RR, DS, MG, TSS, TA	Respiration rate and weight loss were significantly reduced; Maintain table quality	[108]
Sweet cherry (*Prunus avium*)	Diluted 1:3 with distilled water	16 days at 1 °C and 95% RH	RR, WL, C, F, MG	Coating treatment delayed respiration rate, weight loss, color changes, softening and ripening, stem browning, and the growth of microbial populations	[80]
Iranian sour cherries (*Prunus cerasus*)	100%	4 ± 1 °C for 17 days, 65% RH	F, C, TSS, TA, RR, ST	Coated cherries retained the quality parameters such as weight, color, TSS/TA, TA, and firmness during storage	[42]
Peach fruit (*Prunus persica*)	Aloe vera gel with distilled water (1:3)	30 days at 1 °C and 95% RH	F, C, WL, ST, TSS, TA	Coated fruit had reduced weight loss, color change, total soluble solids, and titratable acidity than control	[107]
Fresh-cut kiwi fruit (*Actinidia deliciosa*)	0, 1, 5, 15%	4 ± 1 °C and 75% RH for 12 days	F, C, TPA, TA, TSS, MG, RR, DS, ST	5% coating was found as the most effective in terms of texture profile and sensory analysis	[23]

Table 2 (continued)

Fruits and vegetables (scientific name)	Tested concentrations	Test condition	Key variables studied	Results	References
Fresh-cut lotus root slices (*Nelumbo nucifera*)	0, 25 and 50%	5 ± 1 °C with 85–90% RH for 8 days	WL, BD, PC, SA, OVQ, TAB, EA	50% Aloe gel coating conferred high overall visual quality with reduced weight loss, browning degree, total bacterial count, and enzymatic reactions	[25]
Litchi fruit (*Litchi chinensis*)	50%	20 ± 1 °C and 90% RH for 8 days	pH, TAC, TA, TSS, BI, WL, PC, EA, AA, EL	Coated fruit had reduced weight loss, browning index, peroxidase, and polyphenol oxidase activities, electrolyte leakage, hydrogen peroxide, and malondialdehyde content	[22]
Apple (*Malus domestica*)	0, 1, 5 and 10%	2 °C for 6 months	WL, F, TA, SSC, pH	5 and 10% Aloe vera gel retarded the quality losses of Granny Smith apple	[109]

F firmness, *WL* weight loss, *TPA* textural profile analysis, *TA* titratable acidity, *TSS* total soluble solids, *RR* respiration rate, *AA* ascorbic acid, *C* color, *MG* microbial growth/load, *DS* decay symptoms/spoilage, *ST* sensory test, *Et* ethylene, *MI* maturity index, *PDI* percent disease index, *PC* phenolic compounds, *TAC* total anthocyanin content, *BD/BI* browning degree/index, *SA* scavenging activity, *OVQ* overall visual quality, *TAB* total aerobic bacteria, *EA* enzyme activities, *REL* relative electrolyte leakage, *AVD* aroma volatile development, *TAA* total antioxidant activity

potential alternative to chemical preservatives [107]. 50% Aloe vera coating was found beneficial in delaying the postharvest browning and maintaining the quality of harvested litchi fruit kept at 20 ± 1 °C for 8 days [22]. By reviewing the research discussed above and presented in Table 2, it can be concluded that optimum Aloe gel coating concentration ensuring the best postharvest quality differs among the fresh produce. The performance of an edible coating largely depends on its barrier property to moisture and gases, and the barrier property, in turn, depends on the chemical characteristics and structure of the film-forming substances, the nature of the produce itself, and the storage conditions. Therefore, the ideal concentration of Aloe gel coating should be carefully selected, considering the characteristics of the produce and the storage environment.

Aloe vera coating on minimally processed fruits and vegetables

Minimally processed fruits and vegetables have been achieved popularity in recent years. In the minimally processed industry, the quality of the raw materials has been termed as one of the most important factors. The success of a minimally processed product depends not only on the extended shelf life but also on the fruit's sensory and organoleptic properties [23]. Edible coatings have been applied to the minimally processed fruits to extend the shelf life and retain their nutritional qualities. Four different concentrations of Aloe vera gel [0, 1, 5, 15% (v/v)] were used to study the efficacy of coating in maintaining the quality of fresh-cut packaged kiwi fruit. Aloe vera coated slices showed reduced respiration rate and microbial spoilage during storage at 4 ± 1 °C. Furthermore, fruit slices with 5% coating revealed the best results in terms of texture profile and sensory analysis [23]. To evaluate the effects of edible coating on the quality and shelf life of minimally processed kiwifruit, a comparative study was conducted among the edible coatings made of Aloe vera, chitosan, and sodium alginate. The Aloe vera coating maintains the quality of kiwifruit slices by reducing the microbial proliferation and preventing the tissue softening compared to chitosan and alginate edible coatings [66]. Pomegranate arils treated with Aloe vera coatings resulted in firmness retention, increased levels of total anthocyanins and total phenolics, and lower microbial counts. Moreover, overall sensory analysis scores were higher in Aloe vera treated arils, especially those treated with 100% Aloe vera [82]. Apple slices were coated with Aloe vera gel, shellac individually, or with a combination of shellac and Aloe vera gel. The respiration and ethylene synthesis rates, as well as electrolyte leakage, were reduced by the application of coating treatments. Aloe vera coating alone provided the most reduced polyphenol oxidase and peroxidase activity than the combined treatments of shellac and Aloe vera and shellac alone. Moreover, either alone or in combination, a total soluble solids content of 1.1–1.2% of Aloe vera gel coating was recommended [110]. Minimally processed table grapes dipped into an Aloe vera extract exhibited reduced respiration rate and enzymatic activities with a better sensory score than the untreated grapes [111]. Fresh cut lotus root slices were coated with 0, 25, and 50% Aloe vera gel to be stored at 5 ± 1 °C for 8 days. 50% Aloe vera coated slices exhibited high overall visual quality and suppressed weight loss, browning degree, total bacterial count, and enzymatic reactions [22, 25]. The shelf life of fresh-cut or minimally processed produce is generally short; postharvest treatment with Aloe vera based coating can be beneficial in extending the marketability to a few more days.

Aloe vera gel as a blend with other potential bio-coating materials

Researches have been conducted with Aloe vera gel in combination with other chemical substances to work as a novel edible coating. In order to improve the performance of edible coatings, various natural substances/chemicals have been incorporated. Coating formulations are often made by mixing more than one type of coating, like a mixture of fatty acids, proteins and carboxymethyl cellulose, and commercial coatings. These coating blends were reported to have beneficial effects like extending the shelf life and delaying the onset of fungal infection. However, it is imperative to find a suitable material to improve the efficiency and stability of an edible coating or film. A coating formulation with the best wettability for blueberries was made with 0.5% (w/v) chitosan, 0.5% (w/v) glycerol, 0.1% (w/v) Tween 80 and 0.5% Aloe vera (v/v) liquid fraction. In the case of coated blueberries, microbiological growth and water loss were reduced by 50% and 42%, respectively, after 25 days of storage at 5 °C. Moreover, the blended coating solution extended the fruit shelf life up to 5 days [81]. Papaya fruits were coated with Aloe gel (50%), papaya leaf extract incorporated Aloe gel (1:1, PLEAG), and 2.5% chitosan. It was suggested that the performance of Aloe vera coating could be improved by the incorporation of papaya leaf extract since the PLEAG coating better retained the quality characteristics of papaya and provided extended marketability than the Aloe gel and chitosan counterparts while stored at 30 ± 3 °C and 42–55% RH for 15 days [112]. Calcium chloride (2%) and citric acid (1%) was added to Aloe vera gel to make a coating solution to maintain the quality and safety of table grape (*V. vinifera* L. cv. Askari) stored at 4 °C temperature and 85 ± 5% relative humidity for 35 days. Coated fruits had reduced weight loss and soluble solids content, delayed rachis browning and dehydration, and also better retention of ascorbic acid and titratable acidity than control [113]. On the other hand, a coating made with Aloe vera gel and ascorbic acid [0, 1, 3, and 5% (w/v)] was applied to fresh strawberries to monitor the coating efficiency during storage. The coatings retained the quality parameters and reduced the microbial loads. Aloe vera with 5% ascorbic acid was the most effective among the treatments [114]. Composite edible coating of shellac and Aloe vera gel was formulated for shelf life extension of tomato fruits. The formulated coating was able to delay senescence which was attributed to the restricted changes in respiration and the rate of ethylene synthesis during storage. The developed coating provided longer shelf life of tomatoes (12 days) than the shellac (10 days) and Aloe gel (8 days) coated fruits only during storage at 28 ± 2 °C [115]. Various food-grade additives have been applied to change the coating composition and improve coating properties. The combination of Aloe vera and gum tragacanth as edible coatings was used for bell pepper to determine the coating efficiency on the changes of the physicochemical properties during storage for 30 days. Aloe vera gel and gum tragacanth have beneficial effects in retarding the ripening process, color changes, softening, and shrinkage of stored bell peppers [116]. Similarly, Aloe vera gel-glycerol composite coating helped for the extension of the storage life of strawberries with retention of other quality parameters [117]. Tomatoes were coated with Aloe vera-based edible coating formed by mixing Aloe vera juice with an antioxidant-rich herb, glycerol, cinnamaldehyde an anti-microbial compound, and oleic acid. Coatings studies were conducted using 2% solids on tomatoes (higher solids % may result in anaerobic spoilage due to a very low respiration rate). The research concluded that the edible coating delayed the ripening and extended the shelf life of tomatoes [65]. In a recent study, Aloe vera gel was combined with basil seed mucilage to enhance the hydrophilic properties of the gel coatings to be applied to cold-stored apricot fruits; the coating treatment reduced weight loss, respiration rate, and ethylene production while retained the firmness and bioactive compounds of the stored apricots [118]. As a result, there is a growing interest in the performance and functionally of composite coatings where two or more coating materials with unique functionalities are combined to improve the overall functionality and performance of the coating. Table 3 summarizes a list of functional ingredients added to the Aloe vera gel leading to an enhanced coating matrix.

Combined application of Aloe vera coating and optimum packaging techniques

Aloe vera gel edible coating combined with perforated (24 holes) plastic film packaging helped to gain long storage durability of strawberries with the maintenance of other

Table 3 Examples of functional materials incorporated into Aloe vera coatings

Active bio-coating materials/additives	Commodity	Functions/results	References
Cysteine	Fresh-cut apple (*Malus domestica*)	Worked as an antibrowning agent. Aloe coating formulated with 0.5% cysteine delayed the browning and reduced the microbial populations	[24]
Ascorbic acid and citric acid	Pomegranate arils (*Punica granatum*)	Positive effects on delayed browning and microbial spoilage	[82]
Chitosan and glycerol	Blueberry (*Vaccinium corymbosum* L.)	Microbiological growth and water loss were significantly reduced	[81]
Shellac	Tomato (*Solanum lycopersicum* L.)	Provided optimum barrier properties to the coating; delayed senescence and gave longer shelf life than in the case of shellac and Aloe vera only	[115]
Glycerol and cinnamaldehyde	Tomato (*Solanum lycopersicum* L.)	Glycerol (2%) and cinnamaldehyde (0.2 ml) served as the plasticizing and anti-microbial compound, respectively	[65]
Gum tragacanth	Bell peppers (*Capsicum annuum*)	Gave stability and served as the emulsifier for the coating; coating found beneficial in retarding the ripening process, color changes, softening, and shrinkage during storage	[116]
Papaya leaf extract	Papaya (*Carica papaya*)	Provided additional antimicrobial property to the coating. Papaya leaf extract incorporated Aloe gel (1:1) better retained the quality characteristics of papaya during storage	[112]
Calcium chloride and citric acid	Table grape (*Vitis vinifera*)	Served as an antimicrobial and antibrowning agent. Coated fruits had reduced weight loss and better retained other quality parameters	[113]
Ascorbic acid	Strawberry (*Fragaria ananassa*)	Conferred antibrowning and antioxidant effects. The coatings retained the quality parameters and reduced the microbial load in strawberries	[114]
Shellac	Apple slices (*Malus domestica*)	Contributed to an improved barrier property to the coating matrix. There was reduced respiration, and ethylene synthesis rate and other quality parameters were better retained by the coated slices	[110]
Glycerol	Strawberry (*Fragaria ananassa*)	Coating reduced weight loss, respiration rate, and vitamin C degradation. Moreover, it maintained strawberry color, total soluble solids, hardness, and total acid	[117]
CMC and glycerin	Tomato (*Solanum lycopersicum* L.)	Fresh Aloe vera coating was effective in retaining the safety and quality of tomatoes	[119]
Salicylic acid	Orange fruit (*Citrus sinensis* L.)	Activated a defense system against pathogens, therefore, delayed the postharvest decay. Also, being an antimicrobial compound, it reduced the total microbial count in oranges during storage	[120]
Fagonia Indica Plant extract	Sapodilla fruit (*Manilkara zapota*)	Suppressed the activity of cell wall degrading enzymes and conserved firmness, provided antimicrobial properties to the coating matrix	[31]
Sage essential oil	Tomato fruit (cv. Daphne F1)	The essential oil has antimicrobial and antioxidant activities. 0.1% essential oil maintained the fruit quality during storage with reduced decay symptoms	[121]
Banana starch and chitosan	Strawberries (*Fragaria* ssp)	Reduced water vapor permeability due to the crosslinking effect between Aloe vera and starch molecules, chitosan being highly hydrophobic further added reduced water permeability to the composite coating	[11]

quality characteristics [117]. Similarly, tomatoes coated with Aloe vera and stored in plastic film packaging exhibited microbial safety and postharvest quality retention [119]. Low-temperature storage, together with Aloe vera coating and poly packaging, resulted in the extended marketability of grapes by reducing the moisture loss [102]. However, in a recent study conducted with papaya [122], Aloe vera gel coating together with polythene packaging was suggested to be a poor postharvest treatment, especially when the fruits attain the ripening stage. Further, unperforated polythene packaging could have a more detrimental effect on papaya fruit quality than the perforated counterpart [122]. On the other hand, the combined application of Aloe vera gel and modified atmosphere packaging was reported to be a promising postharvest treatment for cherry laurel fruit as the combined treatment maintained the quality parameters and bioactive compounds of the stored fruits [123]. Overall, a careful selection of a combination of Aloe vera gel coating and an optimum packaging strategy could lead to a desirable postharvest quality of the stored produce.

Challenges associated with Aloe vera coating application and functionality

Different Aloe plants from different geographical locations could have variations in their chemical composition. Therefore, the use of those plants in experiments could result in conflicting observations. Moreover, variation in isolation techniques from laboratory to laboratory for a specific component of Aloe vera extract could lead to that difference. Further, inefficient harvesting, processing, and marketing procedures could lead to undesirable Aloe products. The original structure of the polysaccharide and other bioactive compounds could undergo irreversible changes due to the processing steps. A dehydration temperature of 60 °C modified the physicochemical properties of the Aloe components, especially the storage polysaccharide, acemannan [124]. The structural modifications that occurred due to the high applied temperature could affect the related functional properties of the polysaccharide [124]. Moreover, a high processing temperature not only affects the bioactive and functional properties but also affects the consistency and viscosity of the Aloe gel [125]. Likewise, it has been reported that the Aloe gel polysaccharides are unstable while kept under environmental stress as heat, acidity, and enzymatic reactions [48]. Moreover, following the improper extraction technique of gel from the Aloe vera leaf could lead to bitter products. Besides, a threshold at 20% (w/w) was proposed for sensory acceptance [23]. Also, selecting an optimum coating concentration and formulation for a specific fresh commodity is imperative and often challenging. The high solid concentration of coating could lead to an enhanced physiological loss in the mass of commodities [65]. Besides, inadequate processing techniques could result in very little or virtually no mucopolysaccharides in the aloe products, which is one of the active ingredients in Aloe vera gel [41]. Heat is often applied to let the gel free from bacterial contamination, but high heating for a prolonged time might further deteriorate the bioactive components of the gel with decreased efficiency [126]. Moreover, there is no standard methodology for heat treatment, coating preparation, and application, such as dipping time [18], which may further challenge its industrial implementation. Also, the low film-forming property of the Aloe vera gel prevents its widespread application as edible films and coatings [92].

To minimize the deterioration of the Aloe components and to retain the polymeric substances like polysaccharides, it is important to follow a standardized and steady processing method [48]. For the complete inhibition of microbial growth until 90 days at 4 °C storage, the application of high hydrostatic pressure (HHP) could be an alternative to thermal pasteurization of the Aloe vera gel [125, 127]. Also, precautions should be made so that the freshly harvested leaves immediately go to the processing facilities otherwise should be properly refrigerated to reduce the decomposition of the gel. Overall, understanding the solution's physicochemical and mechanical properties and the resultant film is important in designing an ideal food packaging system.

Conclusions and future approaches

The reduction of postharvest loss of fruits and vegetables remains a challenge throughout the world. The application of edible coatings to the fresh produce can be a potential solution to the problem of postharvest loss. Natural substances with unique antimicrobial or antifungal activities will gain popularity as substitutes for synthetic packaging. Aloe vera gel coatings have been found to prevent water and firmness loss, reduce microbial loads while maintaining the biological and functional properties of the stored fruits and vegetables. Despite the promising performance of Aloe vera coating in the shelf life extension of fresh and minimally processed fruits and vegetables, the commercial applications of this coating are still very limited. Instability of the bioactive components, week film-forming properties, and surface adhesion, etc., might be some of the factors behind its limited use as commercial coatings. Therefore, the study on the characterization of physicochemical properties, mechanical and sensorial properties of Aloe vera gel coatings in response to physical conditions such as pH, temperature, RH, and time, etc., during handling and storage is crucial. The effect on the physiological processes, e.g., respiration, metabolic responses, production of metabolites, etc., of the treated produce during storage should also be considered.

Standardization in coating preparation and application by comparing the effectiveness of the methods used in literature should be the scope of future study. Optimal processing techniques and the incorporation of other natural compounds to achieve ideal film properties is critical in future research. Emulsion type coatings based on Aloe vera gel might exhibit better characteristics and could become a novel trend in the food processing industry. Besides, the inclusion of nanoparticles into the film-forming solution could improve the overall quality of Aloe vera gel-based coatings.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

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