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Advancement and Effectiveness of *Aloe vera* (*Aloe barbadense miller*) and Sodium Alginate Based Natural Coatings for Extending the Shelf Life of Fruits and Vegetables

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

The Preservation of fruits and vegetable freshness is crucial in the agri-food industry to reduce postharvest losses and waste. Edible Coating emerges as a promising approach for extending the shelf life of these perishable goods. This study examines the role of edible coatings, with particular emphasis on *aloe vera* and sodium alginate as sustainable and natural coating agents. Studies demonstrate that these coatings effectively reduce moisture loss, control gas exchange, and inhibit microbial activity, which are critical factors in maintaining product quality. *Aloe vera* and sodium alginate coatings, particularly when enriched with essential oil, significantly enhance antimicrobial properties and preserve texture and color during extended storage. Through process optimization, the study investigates fine-tuning coating methods, ingredient concentrations, and storage conditions to optimize their efficacy. Additionally, quality characterization techniques are explored for quantitatively assessing the impact on freshness, sensory qualities, and overall quality. By addressing postharvest loss challenges, this review highlights *aloe vera* and sodium alginate coatings, and their potential for sustainable food preservation, contributing to reduced food wastage and fulfilling consumer demand for high-quality produce.

Keywords: Edible coating; Aloe vera; sodium alginate; preservation; shelf life.

1. INTRODUCTION

Preserving the freshness and quality of fruits and vegetables is a significant challenge in modern agriculture. Consumers are increasingly concerned with food safety, environmental impact, and the need for minimally processed, high-quality products with an extended shelf life. This demand, driven by busy lifestyles and heightened awareness of health, has spurred interest in natural alternatives to traditional chemical preservation methods. Chemical fungicides, while effective in controlling post-harvest diseases, raise concerns due to their adverse effects on human health and environmental pollution. Residues left on produce contribute to environmental degradation and food safety issues, prompting researchers to seek safer and more sustainable alternatives (Khaliq et al., 2019; Low & Chong, 2022). Natural plant extracts, known for their bioactive compounds like phenols, flavonoids, alkaloids, and terpenoids, have garnered considerable attention as potential agents for preventing post-harvest losses and extending shelf life. These extracts have been traditionally used to combat fungal infections and are seen as an environmentally friendly and health-conscious option compared to synthetic chemicals (Ali et al., 2019; Rastegar et al., 2019). Additionally, consumer demand for products free from chemical preservatives has driven significant interest in developing edible coatings from natural biomaterials. Edible coatings derived from plant-based substances like polysaccharides, proteins, and lipids offer an innovative approach to preserving fruits and vegetables. These coatings act as protective barriers, minimizing quality deterioration by reducing moisture loss, respiration rates, microbial growth, and mechanical damage during handling. By delaying ripening, controlling biochemical changes (such as softening, ethylene production, weight loss, and pigmentation), and preserving sensory and nutritional qualities, plant-based coatings extend shelf life effectively (Alkaabi et al., 2022; Nicolau-Lapena et al., 2021).

Recent advancements in edible coatings focus on tailoring functional properties to meet the specific needs of different types of produce. Notably, both biodegradable and non-toxic, *aloe vera* and sodium alginate have demonstrated potential due to their moisture retention, antioxidant, and antimicrobial properties. This review explores the potential of *aloe vera* and sodium alginate as edible coatings for minimizing post-harvest losses, focusing on their mechanisms for quality preservation, their roles in mitigating biochemical changes, and the broader implications for reducing food waste sustainably.

2. EDIBLE COATINGS

A thin layer called an edible coating, that applied to the outside of fruits to provide a palatable barrier that protects them from environmental factors (Bernard *et al.,* 2020). Edible films or sheets are defined as having a thickness of more than 0.050 mm, whereas edible coatings are defined as having a thickness of less than 0.025 mm (Amaral *et al.,* 2018). In multi-layered packaging systems that also contain non-edible films, edible films can be used as an inner layer that comes into direct contact with food (Dominguez *et al.,* 2019). By dissolving the specified coating materials or compounds in a variety of organic or inorganic solvents, the coating solution can be created. This coating serves the purpose of preserving the food by providing a protective barrier, thus helping to prevent spoilage and deterioration over time (Priya *et a*l., 2023). To meet consumer demand, the food sector should offer fresh fruits that require minimal processing, are palatable with minimal preparation, and can be stored effectively. The demand for edible coatings on fruits is a recent invention to increase shelf life, retain health advantages, and avoid aesthetic and textural degradation. Edible coatings are often composed of natural elements such as protein, lipids, essential oils, polysaccharides, and waxes. The properties of various coating materials vary i.e., lipids are often hydrophobic. As a result, moisture loss is reduced, weight loss is decreased, and fruit ripening is delayed. Edible coatings, acting as thin protective layers, form a shield against moisture, oxygen, and solute formation, ensuring the quality of fruits while also being safe for consumption (Wang *et al.,* 2020). Palatable (edible) coatings, composed primarily of proteins, polysaccharides, or lipids, are directly applied onto the surface of fruits to enhance their quality and shelf life. These thin layers function as a protective screen and reduces chemical, physical, or microbiological alterations. Frequently, the chosen raw materials possess added functional properties, such as antimicrobial or antioxidant characteristics, further enhancing the effectiveness of the edible coatings. Furthermore, these coatings may be enriched with additives, providing a means to enhance both the shelf life and safety of the end product. Thus, coating offers an optimistic approach to thwart deterioration during storage, function as a semipermeable barrier, allowing the passage of carbon dioxide, water vapor, and oxygen. It effectively preventing issues such as water loss, alterations in firmness, or oxidation. Edible coatings are a renewable invention used to enhance the quality and shelf life of crops. These materials act as agents regulating decay rate, weight loss, and the oxidation process, moisture exchange, shelf life, nutritional and sensational attributes of fruit products (Nicolau-Lapena *et al*., 2021).

They are derived from natural substances like proteins, polysaccharides, and lipids. Edible coatings and films have found extensive use in coating fresh commodities. Naturally occurring polysaccharides, including alginate, starch, pectin, chitosan, gums, and hydroxypropyl methylcellulose. Reports indicate that *aloe vera* can significantly prolong the freshness of fresh yield (horticultural product). Various proteins, such as soybean protein isolate, zein, egg protein, milk, and wheat gluten, are employed as edible coatings for fruits and vegetables. Various types of waxes, such as beeswax, carnauba wax, and candelilla wax, find extensive use as lipid-based edible coatings in different applications. Additionally, the field of edible coating research is witnessing increasing interest in composite coatings, which combine two or more basic compounds to augment their functionalities (Sarker & Grift *et al.,* 2021). The review explored the potential use of *aloe vera* and sodium alginate edible coatings, either individually or in combination with other substances, for preserving fruits. With consideration of the current research landscape and advancements in fruit preservation, this review aims to explore the interplay between the composition of *aloe vera* and sodium alginate coatings and their effectiveness as a mechanical barrier. The objective is to provide insight for researchers engaged in postharvest preservation methods.

2.1 Polysaccharide-based Coatings

Over the past few years, there have been remarkable strides in the research domain concerning polysaccharide-based coatings for vegetables and fruit products. The polysaccharide coating technique has the potential to rapidly emerge as a viable and sustainable alternative to conventional packaging methods because of its biodegradable nature (Bersaneti *et al.,* 2021). It inhibits the antimicrobial substances release rate in perishable products i.e., fruits and vegetables (Zhao *et al.,* 2022). It will extend the life span of products by increasing antioxidant activities and enhancing their visual appearance (Duong *et al.,* 2022). Usually, these types of coatings are glasslike (transparent) and have lower calorie content (Hassan *et al.,* 2018). Polysaccharide coatings are commonly applied to fruits and vegetables for protective purposes (Fig. 2). There are various types of gum such as guar gum, xantham gum, Arabic gum, agar and carrageenan. Cellulose derivatives like methylcellulose, carboxymethyl cellulose, hydroxypropyl methylcellulose, and methyl ethyl cellulose have also been utilized for coating fruits and vegetables. (Yousuf *et al.,* 2018; Hassan *et al*., 2018; Salehi. 2020). Major features of starch-based coating are colorless, non-oily, low priced, and easy accessibility. However, some Single polysaccharide-based coatings are difficult to apply in fruits and vegetables due to their low water vapor barrier properties (Florez *et al.,* 2022). Though starch is hydrophilic so primarily it is not suitable for use as a coating material thus plasticizers and emulsifiers are combined to enhance barrier properties (Luchese *et al.,* 2017; Cazon *et al.,* 2017).

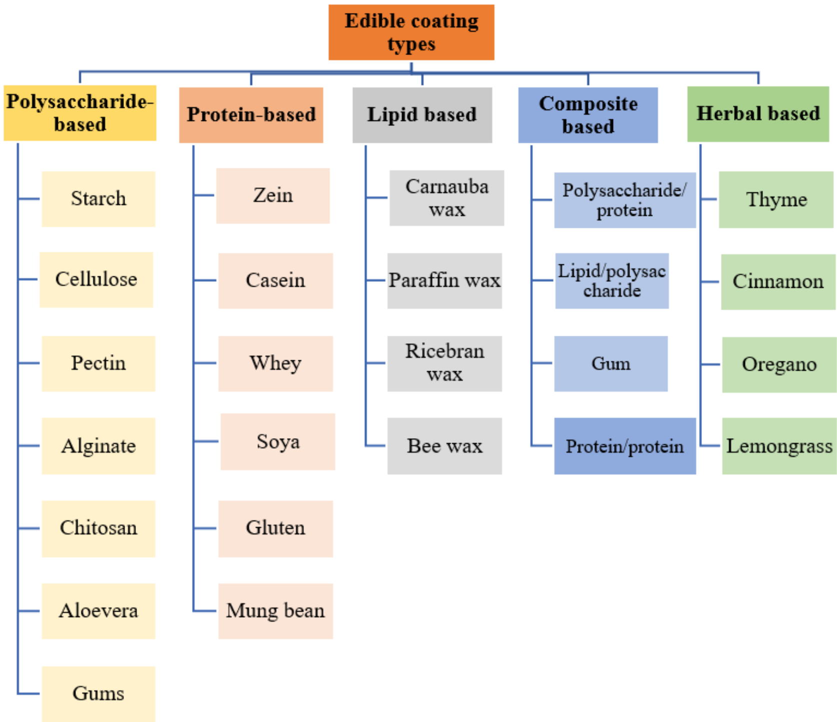

Fig. 1. Various types of edible coating for preserving fruits and vegetables

Table 1. Different polysaccharide-based coating materials and impact on fruit quality

Polysaccharide	Impact	References
Starch	Significantly prevent firmness, preserved color, decreased respiration rate and inhibit ethylene emission, improved permeability and mechanical properties of plum fruit.	Thakur *et al.,* 2018
Pectin	Excellent aroma preservation capability while serving as effective barriers against O_2 and CO_2., Water-soluble, and retard moisture loss; Exhibit transparency and resistance to oil and fats. Maintained overall quality of plum, fresh cut apple, strawberry, blueberry, persimmon etc.	Panahirad *et al.,* 2020
Cellulose	Maintained TPC, flavonoid content, improved shelf life by decreasing color, WL, showed high antifungal properties in strawberries.	Liu *et al.,* 2021
Chitosan	Protects from pathogen, decreases gas exchanges & decay indices, maintained antioxidant activity, improved storage life of grapes, mango.	Nia *et al.,* 2021
Pullulan	Showed mechanical strength, restrained O_2 & CO_2, maintain firmness, WL, vitamin C, preserve color, TA and improved storage life of banana.	Ganduri, 2020

Table 2. Functional properties of *aloe vera* gel

Functional properties	Summary
Moisture retention	Composed of polysaccharide which helps of keep moisture lock in fruits for preservation purposes.
Coating materials	Helps to create to thin protective outer surface layer of fruits and vegetables.
Antioxidant activity	Due to higher antioxidant, it helps inhibit oxidative stress which is responsible for deterioration.
UV shielding	That helps to block damages of food active compounds like lipid, protein, vitamins.
Gas barrier	Restrict penetration of gases like o_2, co_2 from encapsulated materials.
Wound healing	Treated as a medicine for veterinary, skin injuries, scratches, burn etc.

2.1.1 *Aloe vera*

Aloe vera is an annual herbaceous plant that comes from the Asphodelaceae family. It can grow in many regions across the world like Mediterranean region, India, China, Eastern Africa, Arabian-peninsula and wild species are found in Malta, Canary Island, Cyprus, India. It holds up anthraquinones, various types of vitamins, saccharide and also used in different sector like pharmaceuticals, food industry, beauty products also (Radha & Laxmipriya, 2015; Rahman *et al.,* 2017; Sanchez-Machado *et al.,* 2017; Sonawane *et al*., 2021).

Aloe barbadense miller is the common variety of *aloe vera*. Triangular thorns are present across the edges of leaves. About 96% of *aloe vera* are covered with water & remaining 4% carry solid substances that are rich in dietary fiber (73.35%), protein (6.86%), fat (2.91%), ash (16.88%), ascorbic acid (0.004%). Flesh and pulp are obtained from leaves, Flesh can be obtained by washing, peeling, and squeezing and this is greenish-white in colour (Zhang *et al.,* 2018). Scientist expressed that for having these 75 nutrients, sugar, salicylic acid, vitamin and also other bioactive compound, *aloe vera* has a mutual/complementary effect (Vega-Galvez *et al*., 2011). It is colorless, flavorless, odorless, has thick jelly-type substances that contain different components such as flavonoids, chromone, anthraquinone, phenylpropanoids, glycoside, coumarins, anthraquinone, phytosterol, chromone, and phenol derivatives (Kahramanoglu *et al.,* 2019). Anthraquinone and emodine that are present in *aloe vera* have antifungal & antimicrobial traits, as they help to reduce the growth of microorganisms and increase shelf life of food products (Rasouli *et al.,* 2019; Mendy *et al.,* 2019). AV has the capability of protecting food constituents like carbohydrates, protein, and fat from UV light that's why it has been used in alginate/starch-based coating for increased storage of strawberries (Pinzon et al., 2020). It reduces ethylene production, respiration rate, and browning index.

2.1.1.1 Extraction of aloe vera gel

To prepare *aloe vera* gel, it is essential to use freshly harvested, matured leaves that are 3 to 4 years old. Leaves are cleaned thoroughly using a chlorinated solution (25%). The cortex layer of leaves is removed and colorless inner matrix gel known to be hydro parenchyma tissues, is collected. This matrix was homogenized in a blender after filtrated to obtain freshly liquid gel. It has been pasteurized at 70 °C for 45 minutes. After pasteurization, it have to be cooled at ambient temperature (25 ± 2°C). The pH level of the gel is regulated to and upheld at 4.0 through the addition of a precise quantity of citric acid, which is maintained within a range of (4.5 ± 0.1 g/L) (Parven *et al.,* 2020).

2.1.2 Sodium alginate

Alginates are hydrophilic, anionic heteropolysaccharide that are common in nature. They are present as structural components in brown sea weed (phaeophyceae). The pigment found in these algae, namely chlorophyll a and c, are obscured by carotenes and xanthophylls. Their distinctive brown color is mostly by phycoxanthin (xanthophyll) (Abka-Khajouei *et al.,* 2022). It is one of the forms of sodium salt in alginic acid. Though it is not dissolved in water but this sodium alginate natural polysaccharide is water soluble which composed of monosaccharide polymers units such as β-D- mannuronic acid and α-L-guluronic acid units (Wang *et al.,* 2020). It is readily available, low cost, used in gel formation, micro or nano encapsulation which is non-toxic and easily biodegradable in nature though it has effective properties such as film forming, compatibility to living organism, resistance to oil and fat transfer etc (Reyes-Avalos *et al.,* 2016). It acts as ecofriendly synthetic polymer in different industry, namely it has ability to bind lithium-ion battery anodes (Garcia *et al.,* 2018). It has those possibilities to make it an ideal coating material for its specific characteristics like transparency, rheological behaviour, physicochemical property. Alginate and its derivatives have physiological activity that included coagulant, wound healing, antimicrobial, antioxidant (Wang *et al.,* 2019). It combined with essential oil such as thyme, lemongrass, sago etc enhances film forming effectiveness of controlling microbial activity, mechanical flexibility, resistance towards water vapour (Acevedo-Fani *et al.,* 2015).

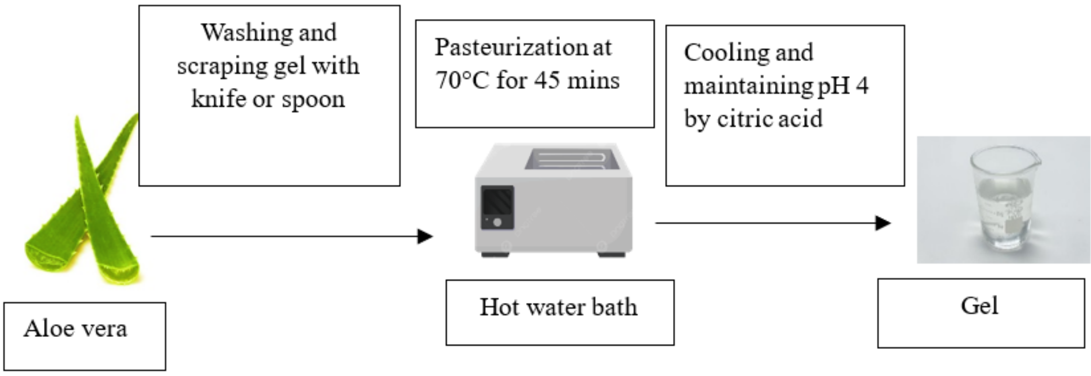

Fig. 2. Flow chart of *aloe vera* gel preparation

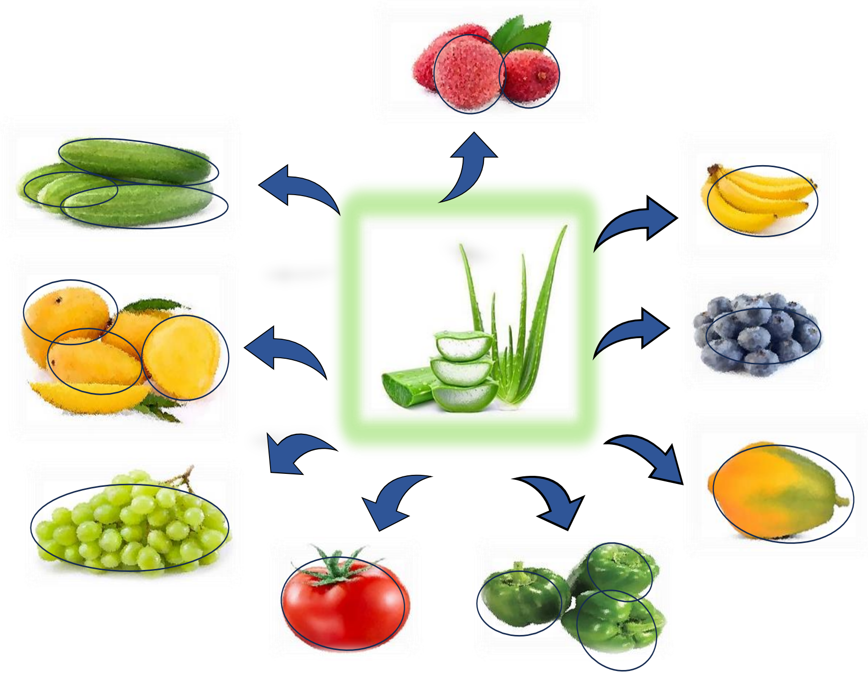

Fig. 3. Application of *Aloe vera* gel edible coating on fresh fruits and vegetables

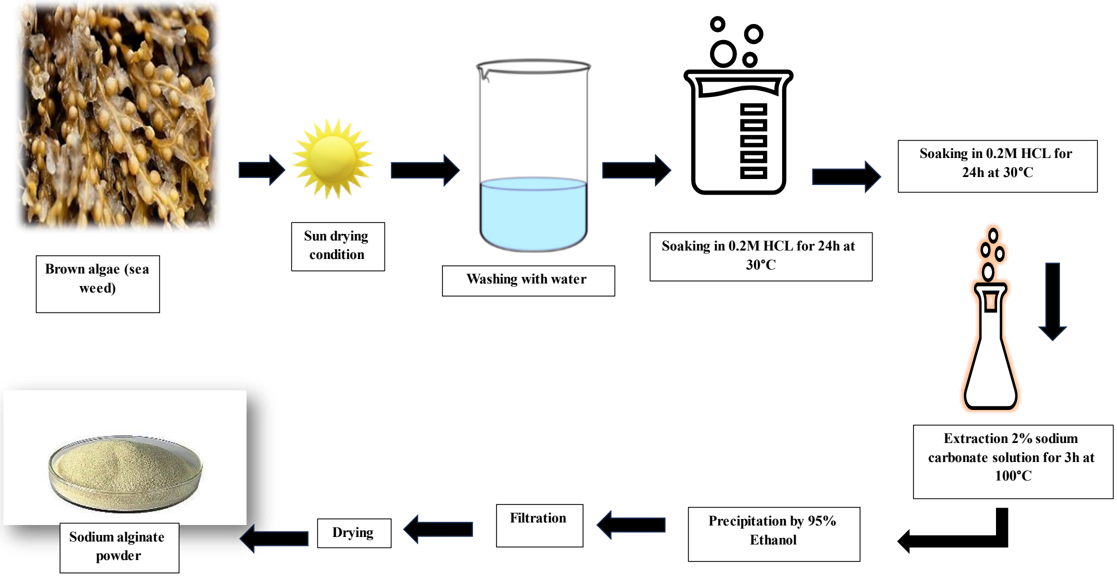

Fig. 4. Extraction of Sodium alginate from brown algae

3. INDIVIDUAL TREATMENT OF ALGINATE CROSS LINKED WITH CALCIUM ION

For improving flexibility plasticizer and cross linkers have been applied. Cross linker used to enhance structural and mechanical properties an+d composing it for different application like encapsulation or gel formation. Alginate films dipped into 2% of zinc chloride (Zn^{+2}), magnesium chloride (Mn^{+2}), calcium chloride (Ca^{+2}), aluminium chloride (Al^{+3}) for checking its effectivity of cross linking on water vapour permeability, radiometric property. Among all crosslinked film Ca^{+2} showed highest tensile strength (TS) in comparison rest of ion. This alteration of TS due to variation in metal ions affinity and strength of ionic bonds that formed with carboxyl group along with alginate chain. During cross linking amount of internal alginate dissolution directly related to film thickness and shrinkage rate. Thus, cross linked alginate hold polymer moreover it will help to improve thickness by creating a network structure for binding the chain. It significantly reduces WVP by restricting movement of chain inside film and lessen the space which is available for passing vapour molecules (Liling *et al*., 2016).

4. EDIBLE COATING TECHNIQUES FOR SHELF-LIFE EXTENSION

Edible coating techniques are the method which is used to create a protective layer on surface of fruits and vegetables. This technique helps preserve quality attributes such as firmness and freshness, ultimately enhancing safety and prolonging the shelf life of products. Several conventional techniques for applying edible coatings have been utilized on fruits and vegetables including dipping, spraying, brushing, vacuum impregnation, panning, freeze thawing, fluidized bed processing method etc (Suhag *et al.,* 2020; Ban *et al.,* 2018; Senturk *et al.,* 2018).

Freeze thawing method is a combination of freezing and thawing operation, this has several applications in food industry like investigation of ribosome assembly, analysis of coating effectiveness, polysaccharide-based hydrogels. Although sometimes in formation of crystal during freezing and melting during thawing process it causes physical damages (Ban *et al.,* 2018). Dipping is most commonly used method for fabricating a semipermeable layer on the exterior part of products. Naturally in this process products have to sink into film which takes time from 30 sec to 5 min to ensuring uniform coverage in all sides of products (Poverenov *et al.,* 2014). Papaya dipped in AV treatment for promoting shelf life up to 14days (Parven *et al.,* 2020). Green chilli dipped into this AV (50%) treatment which reduces postharvest losses (Ul Hasan *et al.,* 2021). In blueberry AV (30%) treatment used which have antifungal properties (Sempere-Ferre *et al.,* 2022).

Spraying is also a regular method, which is achieved by spraying the film in the form of droplets in products via nozzles for conserving fruits and vegetables. This procedure needs not plenty of coating due to uses of high pressure which helps to spread same distribution in products external surface. Although 3 types of spraying techniques which has been used in food industry as well as pressure atomization, air spray atomization, air assisted airless atomization (Valdes *et al.,* 2017; Peretto *et al.,* 2017). Vacuum impregnation method used for improving vitamins, minerals components that are present in food. In this product are partly absorbed in solution and connected to vacuum pump which plays an important role in this process (Senturk *et al.*2018). Fluidized bed processing is a widely utilized method in the food industry, as well as for research purposes. This technique claimed higher amount of coating materials& it is of 3 types are top, bottom, rotatory among them top spray plays most adequate role. In this top fluidized bed, coating solution is applied by spraying with the help of nozzles at low pressure (Priya *et al.,* 2023). In Panning method, foods are settled under a pan in which coating solution are dispersed or splattered & spray gun which is present inside of it start working for the spreading of solution into the products. Pan will be move round till the equal distribution of solution over the products. Once it done it will proceed for drying (Kumar *et al.,* 2022; Suhag *et al.,* 2020). Brushing method depends upon the application of fruit surface with brush, better result depends on several factor like stickiness, density, relative humidity, thickness factor. For getting effective result & less error, skilled worker needed for manual brushing (Shiekh *et al.,* 2021). Electro spraying is an innovative technology, involves atomization of film material in the presence of strong electric field. This process initiated to generate micrometric and submicrometric charge droplet with uniform size particles. When liquid is emitted from the tip of an emitter, it spreads out on the surface, resulting in the creation of a cluster of charged particles referred to as a Taylor cone (Lu *et al.,* 2020). Strawberry coated with sodium alginate by these techniques, which maintains WL, browning (Peretto *et al.,* 2017). In Drop Casting method less amount of coating material has been used. Droplets of solution have been applied on products after that it have to dried for further used (Riera-Galindo *et al.,* 2018). Tomatoes are coated with AV+AL reinforced with $nTiO_2$ for extending the storage life (Salama & Aziz, 2020).

5. PROCESS OPTIMIZATION AND QUALITY CHARACTERIZATION

A comprehensive assessment of edible coatings in the food industry is given by Listsyn *et al.,* (2021), who also include aspects that are crucial for process optimization and quality characterization in order to maintain freshness and prolong shelf life. It ensures that the coating process is tailored to specific needs, leading to improved shelf life and reduced postharvest losses. Optimization of process parameter in fruit coating is very significant and crucial for preserving maintaining freshness and firmness to consumers. Such process involves several factors to achieve better result such as quality, cost effectiveness etc. Applying natural coatings helps increase the storage life of fruits and vegetables, offering insights into optimizing the process and characterizing the coatings for different types of produce.

6. PHYSIO-CHEMICAL QUALITY CHARACTERIZATION OF COATED FRUIT

Appearance: Color is an important feature of fruit coating that gives a general idea about the quality of fruits. Its freshness and firmness showed consumers acceptancy, it plays an essential role in purchasing the item. Also, peel color is the primary factor to check its ripening/maturity, yield quality, and storage time. During storage ethylene production increases and raises the color of fruits which influences the breakdown of chlorophyll, accumulation of anthocyanin, and acceleration of carotenoids. *Aloe vera* in a combination of alginate and chitosan helps to preserve the color in strawberries (Qamar *et al.,* 2018). *Aloe vera* with alginate and $Cacl_2$ restrict papayas' color (Farina *et al.,* 2020), AV with CMS improve color of cucumber (Sarker *et al.,* 2021). *Aloe vera* coating on the color change of hog plum is also documented (Shakil *et al.,* 2023).

Respiration: It is a metabolic process that causes the breakdown of sugar, and starch into small components like H_2O, and CO_2. It is very significant to preserve the effectiveness of tissues and impart protection against degradation of postharvest loss. There are some extrinsic factor and intrinsic factors which affects the respiration rate of plants such as relative humidity, temperature, storage, stage of maturity & type, etc. Among them, temperature is an external factor that causes enzymatic reaction due to high respiration rate by increasing temperature. Temperature & Relative humidity of are interrelated as they are inversely proportional cause moisture loss due to temp which represents weight loss in products. Also, the type & maturity stage influences the rate of respiration as they have variations of different metabolic activity (Kandasamy, 2022). Rastegar & Atrash (2021) experimented with taking 4 types of samples during 4 week storage period AL+AV & SP+AL showed less respiration rate results as this film has the capability of replacing gas transportation, delaying respiration rate, and enhancing storage life. In pomegranate, respiration rate ranges from 9.04 ± 1.06 nmol $kg^{-1}S^{-1}$ to 15.20 ± 1.10 nmol $kg^{-1}S^{-1}$significantly reduced during storage of 15 days these are treated with 10% AV+0.25% CO& 10% AV+0.50%CO concentration showed best in reducing respiration rate (Singh *et al.,* 2022).

Weight loss: It is an important attribute that relates to commercial interest because it can negatively impact the fruit's quality and make it undesirable. Also, less firmness and appearance properties affect market value. Weight loss occurs due to the outer peel or skin of fruits and vegetables. It means vapor pressure between the fruit's interior and air outside, moisture from the fruit tends to escape through the peel which causes weight loss. Shakil *et al.,* 2023 reported that after using AV coating in hog plum it showed best result of maintaining weight loss than paraffin-coated paper board packaging. Also, water loss ranges from 4.13% to 9.37% during a storage period of 12 days. Although AV film-maintained weight loss (7.4%) after storage period of 28days in green chilli (Ul Hasan *et al.,* 2021), blueberry (Sempere-Ferre *et al.,* 2022) also alginate and *aloe vera* combined preserved weight loss in fresh cut apple (Nicolau-Lapena *et al.,* 2021) (Table 3).

Microbial activity: This indicates the presence or growth of microorganisms like bacteria, mold, fungi, etc, which impact in physiological properties and shelf life. Various coating has antimicrobial properties that inhibit growth and maintain freshness and firmness. In fresh-cut apples alginate-ferulic acid combination showed the best result of reducing pathogen L. monocytogenes growth by 2.3 ± 0.4log CFU/g. No improvement in the reduction or growth of S. cerevisiae was observed after 7 days of storage apple (Nicolau-Lapena *et al.,* 2021). In lotus roots AV & ascorbic acid alone or in combination inhibit the growth of bacterial count but AV+AA significantly showed maximum retardation of microbial initiation by <6.0 log CFU/g FW (Ali *et al.,* 2019). AV has antimicrobial properties so it can reduce microorganism growth in blueberries (Sempere-Ferre *et al.,* 2022), AV with CMS combined film has effectiveness in controlling microbes in cucumber (Sarker *et al.,* 2021), also a combination of AV with LEO can inhibit or reduce microorganism in date (Alkaabi *et al.,* 2022).

Antioxidant: Compounds that help to prevent or retard oxidation of fruits and vegetables which causes declination of quality characteristics like color, flavor freshness, firmness, nutritional contents etc. For its effectiveness, it has been used in different processed foods to increase dietary content. Coating such as Gum Arabic (GA) & garlic extract (GE) helps to conserve bioactive compounds like flavonoids, ascorbic acid & phenolics. AV (100%) with GA (10%) concentration resulted in the highest antioxidant 814.6 mmol $kg^{-1}$and GE (20%) with GA (10%) 787.1mmol kg^{-1} showed less antioxidant activity but both concentrations lower than control 821.6mmol $kg^{-1.}$ Days 6 and 15 showed decreasing antioxidants & showed highest on day 3, 9, 12 during storage (Anjum *et al.,* 2020). In pomegranate arils, less changes in radical scavenging activity (RSA) in between control and treated samples. As the days passed RSA decreased day by day during storage of 15 days, although 10% AV with 0.25% Cinamon oil (CO) showed better RSA in comparison to control samples. CO elongated antioxidant activity and introduced better storage life and AV with CO & RO preserved phenolic compounds (Singh *et al.,* 2022).

Total soluble solids & Titrable acidity: It analyzes the concentration of sugar and other soluble components & ensures fruit ripening and maturity stage. TA is used to determine the acidity present in fruits. *Aloe vera* gel coated showed significantly higher TSS than control treatment & lower in acidity in green chili (Ul Hasan *et al.,* 2021). Result of combined treatment after 15 days of storage TSS gradually increased during storage time of 15 days among them control showed the best result (15.33%) in comparison to GA with garlic extract (14.66%) & rest of 2 treatment GA+AV & GA with ginger extract express less TSS in guava (Anjum *et al.,* 2020). TA decreased during storage also after applying coating treatment of AV &Basil oil it has restrict reducing TA in strawberry (Mohammadi *et al.,* 2021).

Table 3. List of AV & AL alone and combined coating formulations of fruits and vegetables

Fruit/ vegetable (scientific name)	Active bio-coating materials/additives	Coating method	Optimum concentration	Storage conditions	Functions/results	References
Mango (Mangifera indica)	Chitosan (CTS)	Dipping	AV-1% CTS- 1%	RT- 12°C (28 d) 25°C (5 d) RH- 80-85%	• Maintained ethylene production, high TPC than CTS (alone) • Retained peel color, firmness • Less spoilage, less degradation of AA, reduce WL, TA, low TSS, high antioxidant activity	Shah & Hashmi, 2020
_	Chitosan Calcium chloride ($Cacl_2$)	Dipping	AV-10% CTS- 1.5% $Cacl_2$- 1.5%	RH- 25°C (21 d) RH- 80%	• Improve quality by minimizing WL, enhance AA, antioxidant enzyme CAT & POD activity, • Slow down PPO enzyme activity, • Maintained color thus extending storage life.	Hajebi seyed *et al.* (2021
_	Guar gum (GG) Spirulina Sodium alginate	Dipping	AV- 20%, 40% AL-10% GG- 1%, 2% Spirulina- 1%, 2%	RT- 12°C (4weeks) RH- 85-90%	• **AV+AL** maintain TPC, flavonoid contents, antioxidant activity, firmness than other treatment. • **AV** treatment resulted highest TA, antioxidant activity. • **SP+AL** showed highest antioxidant activity, lowest respiration rate & WL. • **GA+AL** maintained the peel color.	Rastegar & Atrash, 2021
_	Sodium alginate	Dipping	AL-3%	RT- 15°C (4weeks) RH- 85%	• Showed minimum TSS content • Reduced WL, • Resulted highest AA, • Improve antioxidant enzyme activity SOD, CAT & POD, maintain TPC.	Rastegar *et al.,* 2019
Blueberry (Vaccinium corymbosum)	NA	Dipping	AV- 30%	RT- 21°C (30 d) RH- 85%	• Helps to preserve fruit quality • Reduces antifungal properties • Expand storage life	Sempere-Ferre *et al.,* 2022
Gola Guava (Psidium guajava)	Gum Arabic (GA) Garlic extract (GE)	Dipping	AV- 100% GA- 10% GE- 20%	RT- 25°C (15 d)	• **GA+GE** showed less browning, extend shelf life up to 13days, restrained increasing TSS after storage • **AV+GA** treatment showed highest PH	Anjum *et al.,* 2020
Date (phoenix dactylifera)	Lemongrass essential oil (LEO)	Dipping	AV- 25% LEO- 3%	RT- 25-29°C (28 d)	• Good antimicrobial properties • Controlled moisture and maintained its	Alkaabi *et al*., 2022

Fruit/ vegetable (scientific name)	Active bio-coating materials/additives	Coating method	Optimum concentration	Storage conditions	Functions/results	References
					textural characteristics	
Banana (Musa sp.)	Garlic essential oil (GO)	Dipping	AV- GO- 0.01%	RT- 20°C (15 d) RH- 80-90%	• reduced anthracnose diseases, WL • Controlled firmness • maintained physical appearance, phenolic content, antioxidant activity, soluble solids and maintained quality.	Khaliq *et al.,* 2019
Persimmon (Diospyros kaki Thunb.)	NA	Dipping	AV- 50%	RT-20°C (20 d) RH- 85%	• Minimization of WL, MDA content, TSS • Reduced cell wall degrading enzymes PG, PME, CEL activities through maturation and softening • Reduced oxidative stress.	Saleem *et al.,* 2022
Fresh cut Melon	Glycerol (GL) Citric acid (CA)	Dipping	AV- 100% GL- 2% CA- 0.1%	RT- 4°C (6 d)	• Control WL, TA, AA, TPC • Lowered yeast and mould count • Showed very small change in Ph (5.55-5.68).	Low & Chong, 2022
MD2 Pineapple (Ananas comosus)	NA	Dipping	AV- AL- (Each)	RT- 5°C (16 d) RH- 85%	• **AL** showed effective color than control and **AV** treatment, • Extended shelf life, • Improved adhesion, • No significant changes in firmness in between coated and control treatment.	Yong *et al*., 2022
Strawberry (Fragia ananassa)	Chitosan Banana Starch (BS) Citric acid Sorbitol	Dipping	AV- 20% CTS- 2% BS- 3% CA- 2%	RT-5-7°C (12 d) RH- 50-60%	• Reduced decay rates, water vapour loss, • AV extended storage life up to 15days • Maintained antimicrobial properties.	Pinzon *et al.,* 2020
_	Basil essential oil (BO)	Dipping	AV- BO-500µL L^{-1} & 1000µL L^{-1}	RT- 4°C (12 d) RH- 85%	• Reduced respiration rate, • Decreases WL, • Controlled TA, flavor & color	Mohammadi *et al.,* 2021
_	Chitosan Sodium alginate	Dipping	AV- CTS- 2% AL- 2% (Each)	RT- 5-7°C (12 d) RH- 50-60%	• **AV** treatment preserve color, firmness, TA, TPC, AA, antioxidant activity & reduced WL, antimicrobial, and antifungal properties. • AV &CTS showed lowest decay indices.	Qamar *et al.,* 2018

Fruit/ vegetable (scientific name)	**Active bio-coating materials/additives**	**Coating method**	**Optimum concentration**	**Storage conditions**	**Functions/results**	**References**
_	Sodium alginate	Electro spraying	AL-2%	RT- 7.5°C (13 d) RH- 90%	• Raises transfer efficiency. • Provide uniform coating. • Maintain moisture loss, browning, extend storage time.	Peretto *et al.,* 2017
_	Sodium alginate Hydroxyethyl cellulose (HEC)		HEC-1% AL-0.5%, 1.5%	RT- 25°C (8 d) RH- 80%	Expand shelf life up by reducing color, WL, working against antifungal properties, HEC with AL both treatments preserved TPC, flavonoid content.	Liu *et al.,* 2021
Apricot (Prunus armeniaca)	Basil seed mucilage (BSM)	Dipping	AV- 30% BSM- 0.1% (Alone or combination)	RT- 2°C (28 d) RH- 85-90%	• **AV+BSM** treatment retard ethylene production, maintained firmness, • BSM preserved TA & TPC, improve TSS, antioxidant activity, appearance.	Nourozi & Sayyari, 2020
Peach	Chitosan	Dipping	AV-30% CTS-1.5%	RT- 3°C (36 d) RH- 85-90%	• showed best result of maintaining firmness, color, TSS, TA, TPC, antioxidant activity.	Aboryia *et al.,* 2022
Fresh cut Kiwi (Actinidia deliciosa)	Hydroxypropyl cellulose (HPMC) Lemongrass oil	Dipping	AV-40% HPMC- 0.1% LEO- 1% AV+HPMC AV+LEO	RT- 4°C RH- 90%	• **AV** & **HPMC**-based edible coatings elongated shelf life, preserving quality • **LEO** and **AV** altered taste. • **AV** with antioxidants and gelling agents proved most effective.	Passafiume *et al.,* 2020
Litchi (Litchi chinensis)	NA	Dipping	AV- 50%	RT- 20°C (8 d) RH- 90%	• Reduce WL, MDA content, browning index, • Showed higher anthocyanin content, TPC prevent water loss, cell damage, • Acts as a good barrier in products.	Ali *et al*., 2019
Table Grapes (Vitis vinifera L.)	Chitosan	Dipping	AV- 33% CTS- 3% (applied before harvesting)	RT- 4°C	• Great effect on maintaining weight loss, TSS, TA, PH during storage time. • Maintain antioxidant activity, TPC, POD, vitamin C & anthocyanin content.	Nia *et al*., 2021
Pomegranate arils (Punica granatum)	Cinnamon oil (CO) Rosehip oil (RO)	Dipping	AV- 10% CO- 0.25% (Combined) RO- (0.25%, 0.50%)	RT- 5°C (15 d) RH- 95%	• **AV+RO** delayed ethylene production • **AV+CO** significantly reduced microbial load & maintained AA content	Singh *et al*., 2022

Fruit/ vegetable (scientific name)	Active bio-coating materials/additives	Coating method	Optimum concentration	Storage conditions	Functions/results	References
Tomato (Solenum lycopersicum L.)	Sage oil (SO)	Dipping	AV- 10% SO-0.1%	RT- 11°C (14 d) RH- 90%	• Decrease ripening, WL TA, color • Maintained the quality of product	Tzortzakis *et al.,* 2019
_	Chitosan	Dipping	AV-1%, 2% CTS-1%, 2%	RT- 4°C (6weeks)	• AV (1%) with AL (1%) preserved lycopene content, TA, AA, expanded shelf life up to 42days, highest TSS, antioxidant activity.	Khatri *et al.,* 2020
Cucumber (Cucumis sativus)	Carboxy-methyl cellulose (CMS)	Dipping	AV- 30% CMS- 1%	RT- 15°C (20 d) RH- 86%	• Maintain color, firmness, WL, TSS, & decreased fungal growth	Sarker *et al*., 2021
Fresh cut apple	Ferulic acid (FA) Sodium alginate	Dipping	AV- 40% AL- 1.25% FA- 1%	RT- 5°C (7 d) RH- 50%	• **AV+FA, AL, AL+FA** showed less WL, no changes in texture, PH (3.9) during storage, **FA, AV** reduce browning, • **FA+AL** decreases microbial activity of L. monocytogenes pathogen, preserve TPC, antioxidant activities & extend shelf life.	Nicolau-Lapena *et al*., 2021
Rambutan	NA	Spraying	AV-10%	RT- 10°C (10d)	• Maintain freshness, peel color, texture, reduced respiration rate.	Darmawati *et al.,* 2019
Papaya (Carica papaya)	Sodium alginate Thyme oil (THO) Oregano essential oil (OEO)	Dipping	AL-2% THO-1% OEO-1%	RT- 4°C (12 d)	• Improved WL, decreased respiration rate, showed less changes in Ph, maintained taste & aroma, • THO & OEO treatment slowdown microbial activity & rheological properties.	Tabassum & Khan, 2020
_	NA	Dipping	AV-50%	RT- 28°C (15 d) RH- 68-70%	• Observed highest TPC at 9th days, flavonoid content after 15days, highest Ph (6.04) but decreases as the end of storage period • Maintained WL, firmness, ripening, and protection from pathogens.	Mendy *et al*., 2019
_	NA	Dipping	-	RT- 25°C (12 d) RH- 80-85%	• Slowdown color development • Preserved WL (11.7%), moisture content (89.9%) up to storage	Parven *et al.,* 2020

Fruit/ vegetable (scientific name)	Active bio-coating materials/additives	Coating method	Optimum concentration	Storage conditions	Functions/results	References
					• Produce less TSS, TA • Maintained yield quality & extended storage life.	
_	Calcium chloride Sodium alginate	Dipping	AV-30% AL-1.5% CaCl2-5%	RT- 5°C (12d) RH- 90%	• **AV** delayed color loss and ripening, conserved stiffness • **AL** provides oxygen barrier, reduces respiration rate, maintained firmness.	Farina *et al*., 2020
Sapodilla (Manilkara zapota)	Fagonia cretica (FC) plant extract	Dipping	AV- 50% & 100% FC- 1%	RT- 20°C (12 d) RH- 70-75%	• **AV** (100%**) + FC** Treatment controlled WL, firmness, decay indices, retard changes of TSS, maintained higher Ph, preserve AA • **AV** (50%,100%) + **FC** sustained flavonoids, TPC	Khaliq *et al.,* 2019
Green Chilli (Capsicum annum L.)	NA	Dipping	AV- 50%	RT- 10°C (28 d) RH- 85-90%	• Minimizes the postharvest loss by extending the shelf life, respiration rate • maintained POD, SOD, CAT activities and lowering water loss and diseases etc	Ul Hasan *et al.,* 2021
Green capsicum (Capsicum annum)	Frankincense oil (FO)	Dipping	AV-66.7% AL-33.3% FO-6%	RT- 25°C (16 d) RH- 52%	• Preserved UV barrier, water barrier properties, antifungal and antibacterial characteristics • maintains weight loss • improves sensory properties	Salama & Aziz, 2021
Lotus roots slices (Nelumbo nucifera)	Ascorbic acid (AA)	Dipping	AV- 50% AA- 1%	RT- 20°C (5 d) RH- 85-90%	• Slow down browning, microbial activity, H_2O_2, O_2 content • Maintained MDA, POD activities • Controlled CAT, SOD enzyme activities & enhance the quality of products.	Ali *et al.,* 2020
Button Mushroom (Agaricus bisporus)	Orange peel essential oil (Eos)	Dipping	AV- 50% Eos- 1500 µL/L	RT- 4°C (16 d) RH- 90%	• Delayed respiration rate • Restrained browning • Improved TSS, TPC	Kumar *et al*., 2023

RT- Room temperature, RH- Relative humidity, AL- Alginate, AV- Aloe vera

Shelf life: It is a critical factor for determining the quality of food products and whether it is suitable for consumers or not. In guava, combined treatment of GA with garlic extract showed a maximum shelf life up to 13 days, and control showed a minimum shelf life but lower than GA with AV treatment (Anjum *et al.,* 2020). In papaya, *aloe vera* gel introduced a maximum shelf life of up to 14 days while the control showed a minimum storage period of 7 days (Parven *et al.,* 2020). Combined treatment of AV (66.7%) alginate (33.3%) with FO (6%) showed its capability of maintaining a storage life of up to 16 days in green capsicum. Also, this treatment doesn't induce any in organoleptic alterations, maintains antimicrobial properties (Salama & Aziz, 2021).

Toxicology, safety, and environmental impact: The assessment of toxicology and safety is primary in the application of edible coatings, especially those derived from natural materials such as *aloe vera* and sodium alginate. Both substances are generally regarded as safe (GRAS) for consumption, with extensive historical use in food and pharmaceutical applications. *Aloe vera* is recognized for its health benefits, including antimicrobial and antioxidant properties, and studies have confirmed that its use as a coating does not introduce harmful residues into food products (Nicolau-Lapena *et al.,* 2021; Passafiume *et al.,* 2020). Sodium alginate, sourced from brown seaweed, is similarly safe and widely utilized as a food thickening and gelling agent (USFDA). Regulatory bodies, including the U.S. Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA), have evaluated these substances and affirmed their suitability for food applications. Incorporating edible coatings into food preservation not only enhances safety but also contributes positively to environmental sustainability. Unlike conventional synthetic packaging materials, edible coatings made from natural, biodegradable substances reduce plastic waste and environmental pollution (Pei *et al.,* 2024). The biodegradability of *aloe vera* and sodium alginate means they can decompose without harming ecosystems, promoting a more sustainable approach to food packaging (Da Silva Rios *et al.,* 2022). However, it is essential to consider potential allergens associated with specific natural additives or essential oils that may be incorporated into the coatings. Comprehensive safety assessments are necessary to ensure that final products remain free from contaminants and safe for consumer use (Visan & Negut.2024). Ongoing research into the long-term effects of these coatings on health and the environment will further bolster their acceptance and implementation in food preservation practices.

7. CONCLUSION

The combined coating of *aloe vera* and sodium alginate can provide several benefits when applied to fruits or other food products. Both of them are natural & eco-friendly, which helps to conserve nutritional content and other physio-chemical properties like weight loss, AA, TPC, antioxidant activity, antimicrobial properties etc. This endorsed that application of this composite coated material enhance the postharvest quality of food products. In essence, the review paper aims to provide a comprehensive understanding of the challenges in postharvest preservation, the role of coatings in addressing these challenges, and the specific benefits and optimization strategies associated with *aloe vera* and sodium alginate coatings.

DATA AVAILABILITY

All the data is included in the manuscript.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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