

## Original Research Article

### Advanced Preservation of Fruits and Vegetables Using Innovative Coating Techniques: Emphasizing Aloe Vera and Sodium Alginate

#### Abstract

Preserving fruit and vegetable freshness is crucial in the agri-food industry, as postharvest losses contribute to food waste and economic inefficiency. Edible Coating materials emerge as a promising avenue for extending the shelf life of these perishable goods. This study conducts a thorough examination of the role coatings play in fruit and vegetable preservation, with particular emphasis on utilizing aloe vera and sodium alginate as natural and sustainable coating agents. It explains the multifaceted functions of coatings in food preservation, highlighting their ability to act as barriers against moisture loss, gas exchange, and microbial activity. The review further explores the diverse array of coating materials available, underscoring the distinctive qualities of aloe vera and sodium alginate in bolstering the quality and longevity of fruits and vegetables. Through process optimization, the study investigates fine-tuning coating methods, ingredient concentrations, and storage conditions to optimize their efficacy. Moreover, it examines quality characterization techniques as fundamental tools for quantitatively assessing the impact of coatings on the texture, color, and overall quality of coated produce. Special attention is given to utilizing aloe vera and sodium alginate coatings to tackle postharvest loss challenges. The study emphasizes the potential for achieving sustainable practices in food preservation, thereby reducing food wastage and meeting the global demand for fresh, high-quality produce.

**Keywords:** *Edible coating, Aloe-vera, Sodium alginate, Preservation, Shelf life*

#### 1. Introduction

Preserving the freshness and quality of fruits and vegetables post-harvest is a significant challenge in the modern agricultural landscape. With rising consumer concerns over food safety, environmental impact, and the desire for minimally processed products, there is a growing demand for natural alternatives to traditional preservation methods. Chemical fungicides, which have long been used to prevent post-harvest diseases, are increasingly

criticized due to their adverse effects on human health and the environment. The residues left on produce not only raise safety concerns but also contribute to environmental pollution, prompting researchers to seek safer, sustainable alternatives. Natural plant extracts, known for their bioactive compounds like phenols, flavonoids, and alkaloids, have garnered considerable attention in recent years as potential agents for extending shelf life and preventing post-harvest losses. These compounds have been traditionally used to combat fungal infections in produce, offering a more environmentally friendly and health-conscious approach compared to synthetic chemicals. The increasing consumer demand for high-quality, fresh produce that is free from chemical preservatives has driven significant interest in the development of natural edible coatings.

Edible coatings derived from plant-based biomaterials, such as polysaccharides, proteins, and lipids, provide an innovative solution to the challenges of preserving fruits and vegetables. These coatings form a protective barrier that minimizes quality deterioration by reducing moisture loss, respiration rates, microbial growth, and mechanical damage. As a result, they effectively prolong shelf life while maintaining the sensory and nutritional qualities of fresh produce. In particular, aloe vera and sodium alginate, both natural and biodegradable, have shown promise as coating materials due to their moisture retention, antioxidant, and antimicrobial properties. This review explores the potential of aloe vera and sodium alginate as edible coatings for extending the shelf life of fruits and vegetables. The examination on their specific roles in minimizing post-harvest losses, the mechanisms through which they preserve the quality of produce, and the advancements in the application of these coatings is studied. By providing insights into process optimization and quality characterization, this review aims to highlight their potential in addressing the global challenge of food waste through sustainable preservation methods

## **2. Edible coating**

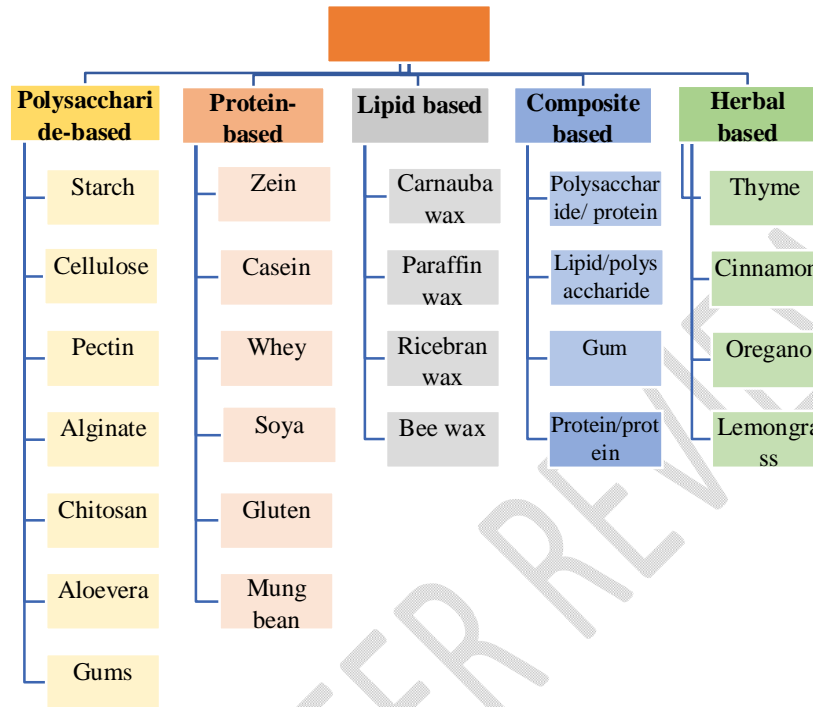
Edible coatings are thin layers of edible material applied directly onto the surface of fruits and vegetables to serve as a protective barrier, extending their shelf life (Priya et al., 2023). These coatings minimize quality degradation by reducing moisture loss, delaying ripening, controlling respiration rates, and preventing microbial growth (Wang et al., 2020; Nicolau-Lapena *et al.*, 2021). Their use has gained significant attention due to the rising demand for natural, biodegradable alternatives to synthetic packaging, which often contributes to environmental pollution (Sarker & Grift et al., 2021). Edible coatings are

primarily composed of natural materials such as proteins, polysaccharides, lipids, or their combinations. Each component brings unique properties to the coating. For instance, lipid-based coatings are highly effective in reducing moisture loss due to their hydrophobic nature, while polysaccharide and protein-based coatings provide good gas barriers. However, the optimal formulation of an edible coating often requires combining these materials to balance moisture retention, mechanical strength, and gas permeability, all while maintaining the sensory qualities of the food. Polysaccharides, such as alginate, starch, pectin, and chitosan, have been extensively studied as coating materials due to their ability to form transparent, breathable films that protect the food without affecting its appearance or taste. Alginate, derived from brown seaweed, is particularly popular due to its film-forming properties, biodegradability, and ability to be cross-linked with calcium ions for added strength. Sodium alginate-based coatings have been shown to preserve fruit firmness, reduce respiration rates, and delay ethylene production, making them an effective solution for maintaining the quality of fresh produce.

Aloe vera gel is another promising edible coating material, known for its high moisture content and bioactive compounds such as polysaccharides, phenolics, and vitamins. These properties make aloe vera an excellent candidate for preserving the freshness and extending the shelf life of fruits and vegetables. Aloe vera has demonstrated antimicrobial and antioxidant activity, which helps prevent microbial growth and oxidative damage. Studies have shown that aloe vera-based coatings can significantly reduce weight loss, control ethylene production, and maintain the color and texture of coated produce. Moreover, the combination of aloe vera with other edible coating materials like sodium alginate can further enhance its functionality. For instance, the addition of sodium alginate improves the structural integrity of the coating, making it more resistant to mechanical damage while also enhancing moisture retention. This composite coating forms a semipermeable barrier that regulates gas exchange, thus delaying ripening and prolonging the post-harvest life of fruits and vegetables.

Edible coatings not only protect the produce from external factors but also offer a medium for incorporating additional functional properties. Antimicrobial agents, antioxidants, and other bioactive compounds can be integrated into the coating to further improve food safety and quality. The use of natural essential oils or plant extracts in combination with aloe vera and alginate coatings has been explored to boost the antimicrobial efficacy of the coatings, offering an even greater defense against spoilage and decay. Overall, the development of edible coatings using natural substances like aloe vera and sodium

alginate presents a sustainable approach to reducing post-harvest losses, enhancing food quality, and addressing the global demand for environmentally friendly preservation techniques.



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

### 2.1 Polysaccharide-based coating

Over the past few years, there have been remarkable strides in the research domain concerning polysaccharide-based coatings for vegetables and fruit products. Due to its advantages, the polysaccharide coating technique has the potential to rapidly emerge as a viable and sustainable alternative to conventional packaging methods (Bersaniet *et al.*, 2021). As it is not harmful to the atmosphere, is biodegradable, and has different kinds of resources. It inhibits the antimicrobial substances release rate in perishable products i.e., fruits and vegetables (Zhao *et al.*, 2022). It will extend 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. That are listed in Fig 2, there are various types of gum such as guar gum, xantham gum, Arabic gum, agar and carrageenan. Yet, cellulose derivatives like methylcellulose, carboxymethyl cellulose, hydroxypropyl methyl cellulose, 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 in nature so primarily it is not suitable for using as a coating material thus plasticizers and emulsifiers are combined to enhance barrier properties (Luchese *et al.*, 2017; Cazon *et al.*, 2017).

**Table 1.** Different coating materials and impact on fruits 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 <i>et al.</i> , 2018
Pectin	Excellent aroma preservation capability while serving as effective barriers against O <sub>2</sub> and CO <sub>2</sub> , Water-soluble, retard moisture loss; Exhibit transparency and resistance to oil and fats. Maintained overall quality of plum, fresh cut apple, strawberry, blueberry, persimmon etc.	Panahirade <i>et al.</i> , 2020
Cellulose	Maintained TPC, flavonoid content, improved shelf life by decreasing color, WL, showed high antifungal properties in strawberries.	Liu <i>et al.</i> , 2021
Chitosan	Protects from pathogen, decreases gas exchanges & decay indices, maintained antioxidant activity, improved storage life of grapes, mango.	Nia <i>et al.</i> , 2021
Pullulan	Showed mechanical strength, restrained O <sub>2</sub> & CO <sub>2</sub> , maintain firmness, WL, vitamin C, preserve color, TA and improved storage life of banana.	Ganduri, 2020

### 2.1.1 Aloe vera

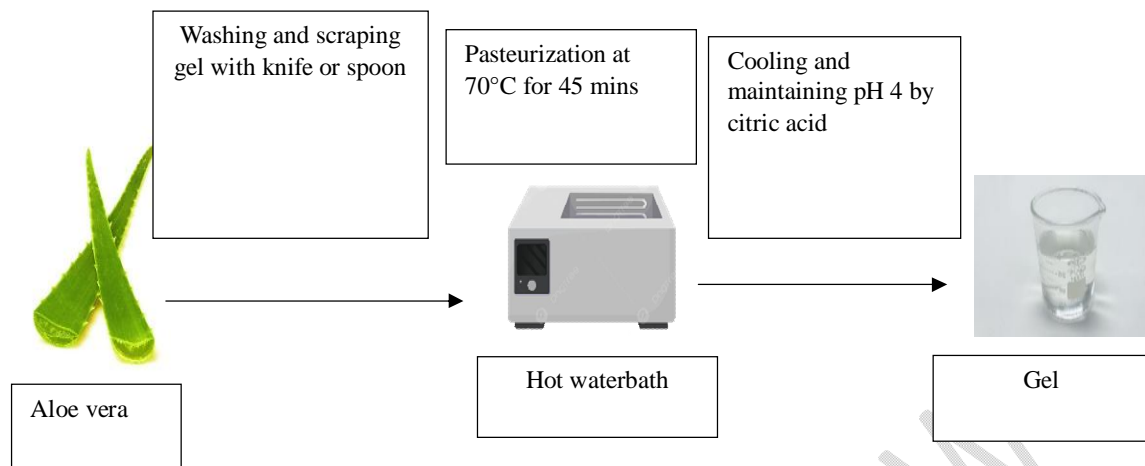
Aloe vera is an annual herbaceous plant commonly called as ghrirkumari/gheegwar that came from the asphodelaceae family. It can grow in many regions across the world like Mediterranean region, India, China, Eastern Africa, Arabian-peninsula and wilds species found in Malta, Canary Island, Cyprus, India. It holds up anthraquinones, various types of vitamins, saccharide & 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).

**Table 2.** Functional properties of aloe vera gel

<b>Functional properties</b>	<b>Summary</b>
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.

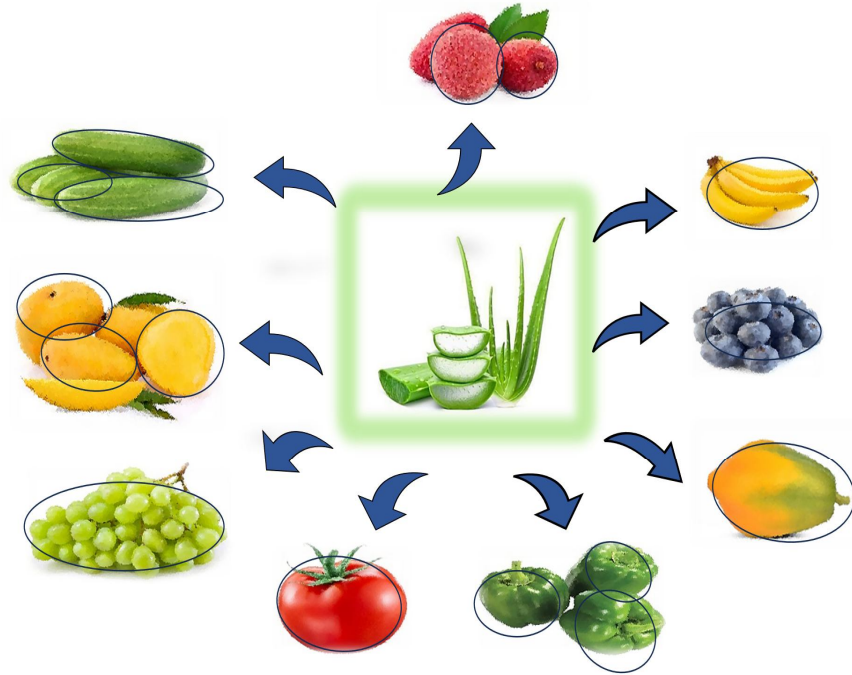
#### **2.1.1.1** Extraction of aloe vera gel

To prepare aloe vera gel, it requires employing freshly harvested matured leaves of 3-4yrs age. Leaves are cleaned thoroughly using chlorinated solution (25%). Cortex layer of leaves is removed and colorless inner matrix gel known to be hydro parenchyma tissues, are collected. This matrix homogenised in blender after filtrated to obtained freshly liquid gel. It has been pasteurized at 70 °C for 45mins. After pasteurization it have to be cooled at ambient temperature ( $25 \pm 2^\circ\text{C}$ ). 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 ( $4.5 \pm 0.1$  g/L) (Parven *et al.*, 2020).



**Fig 2.** Preparation of aloe vera gel.

*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% carried solid substances that are rich in dietary fibre (73.35%), protein (6.86%), fat (2.91%), ash (16.88%), ascorbic acid (0.004%). Flesh & pulp obtained from leaves, Flesh can be obtained by washing, peeling, squeezing and this is greenish white in colour (Zhang *et al.*, 2018). Scientist expressed that for having these 75 nutrients, sugar, salicylic acid, vitamin & also other bioactive compound, aloe vera have mutual/complementary effect (Vega-Galvez *et al.*, 2011). It is colorless, flavorless, odourless, have 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 emodin that are present in aloe vera have antifungal & antimicrobial traits, as they help to reduce the growth of microorganism and increased shelf life of food products (Rasouli *et al.*, 2019; Mendy *et al.*, 2019). AV have capability of protecting food constituents like carbohydrate, protein, fat from UV light that's why it has been used in alginate/starch-based coating for increase storage of strawberries (Pinzon *et al.*, 2020). It reduces ethylene production, respiration rate, browning index.

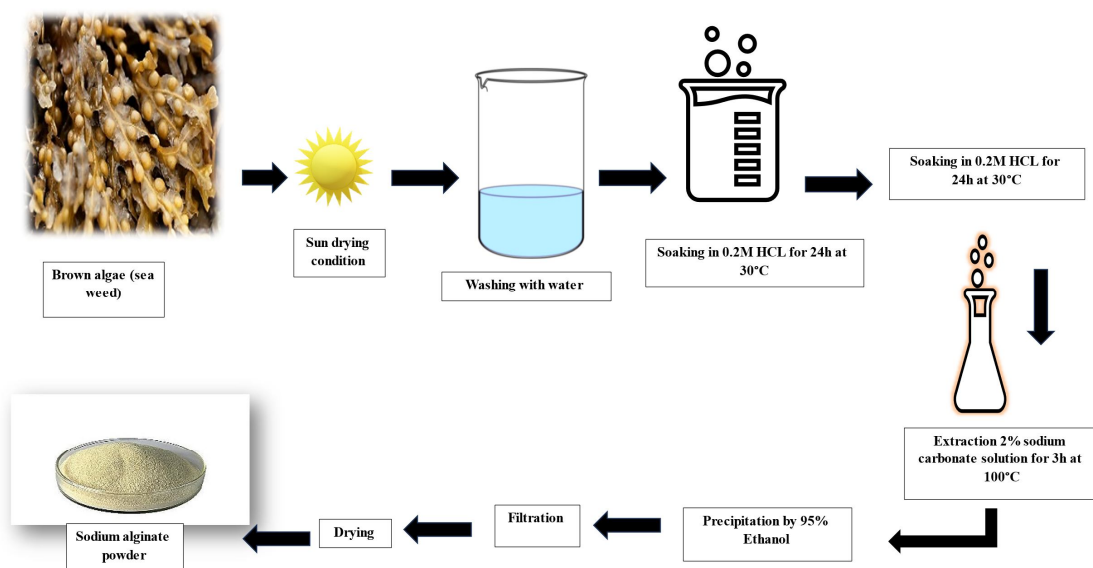


**Fig 3.** Application of aloe vera gel edible coating on fresh fruits and vegetables

### 2.1.2 Sodium alginate

It is natural polysaccharide which has been extracted from brown sea weed, 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 is composed of monosaccharide polymer units such as  $\beta$ -D- mannuronic acid and  $\alpha$ -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 an ecofriendly synthetic polymer in different industries, namely it has the ability to bind lithium-ion battery anodes (Garcia *et al.*, 2018). It has the 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 includes coagulant, wound healing, antimicrobial, antioxidant (Wang *et al.*, 2019). It combined with essential oils 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 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 and 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

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 (Poverenovet *et al.*, 2014). Papaya dipped in AV treatment for promoting shelf life up to 14 days (Parven *et al.*, 2020). Green chilli dipped into this AV (50%) treatment which reduces postharvest losses (UI 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<sub>2</sub> for extending the storage life (Salama & Aziz, 2020).

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**Table 3.** List of single and combined coating formulations for 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%	<ul style="list-style-type: none"> <li>Maintained ethylene production, high TPC than CTS (alone)</li> <li>Retained peel color, firmness</li> <li>Less spoilage, less degradation of AA, reduce WL, TA, low TSS, high antioxidant activity</li> </ul>	Shah & Hashmi, 2020
–	Chitosan Calcium chloride (CaCl <sub>2</sub> )	Dipping	AV-10% CTS- 1.5% CaCl <sub>2</sub> - 1.5%	RH- 25°C (21 d) RH- 80%	<ul style="list-style-type: none"> <li>Improve quality by minimizing WL, enhance AA, antioxidant enzyme CAT &amp; POD activity,</li> <li>Slow down PPO enzyme activity,</li> <li>Maintained color thus extending storage life.</li> </ul>	Hajebiseyed <i>et al.</i> (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%	<ul style="list-style-type: none"> <li><b>AV+AL</b> maintain TPC, flavonoid contents, antioxidant activity, firmness than other treatment.</li> <li><b>AV</b> treatment resulted highest TA, antioxidant activity.</li> <li><b>SP+AL</b> showed highest antioxidant activity, lowest respiration rate &amp; WL.</li> <li><b>GA+AL</b> maintained the peel color.</li> </ul>	Rastegar & Atrash, 2021
–	Sodium alginate	Dipping	AL-3%	RT- 15°C (4weeks) RH- 85%	<ul style="list-style-type: none"> <li>Showed minimum TSS content</li> <li>Reduced WL,</li> <li>Resulted highest AA,</li> <li>Improve antioxidant enzyme activity SOD, CAT &amp; POD, maintain TPC.</li> </ul>	Rastegar <i>et al.</i> , 2019

Blueberry ( <i>Vaccinium corymbosum</i> )	NA	Dipping	AV- 30%	RT- 21°C (30 d) RH- 85%	<ul style="list-style-type: none"> <li>• Helps to preserve fruit quality</li> <li>• Reduces antifungal properties</li> <li>• Expand storage life</li> </ul>	Sempere-Ferre <i>et al.</i> , 2022
Gola Guava ( <i>Psidium guajava</i> )	Gum Arabic (GA) Garlic extract (GE)	Dipping	AV- 100% GA- 10% GE- 20%	RT- 25°C (15 d)	<ul style="list-style-type: none"> <li>• <b>GA+GE</b> showed less browning, extend shelf life up to 13days, restrained increasing TSS after storage</li> <li>• <b>AV+GA</b> treatment showed highest PH</li> </ul>	Anjum <i>et al.</i> , 2020
Date (phoenix <i>dactylifera</i> )	Lemongrass essential oil (LEO)	Dipping	AV- 25% LEO- 3%	RT- 25- 29°C (28 d)	<ul style="list-style-type: none"> <li>• Good antimicrobial properties</li> <li>• Controlled moisture and maintained its textural characteristics</li> </ul>	Alkaabi <i>et al.</i> , 2022
Banana ( <i>Musa sp.</i> )	Garlic essential oil (GO)	Dipping	AV- GO- 0.01%	RT- 20°C (15 d) RH- 80- 90%	<ul style="list-style-type: none"> <li>• reduced anthracnose diseases, WL</li> <li>• Controlled firmness</li> <li>• maintained physical appearance, phenolic content, antioxidant activity, soluble solids and maintained quality.</li> </ul>	Khaliq <i>et al.</i> , 2019
Persimmon ( <i>Diospyros kaki</i> Thunb.)	NA	Dipping	AV- 50%	RT-20°C (20 d) RH- 85%	<ul style="list-style-type: none"> <li>• Minimization of WL, MDA content, TSS</li> <li>• Reduced cell wall degrading enzymes PG, PME, CEL activities through maturation and softening</li> <li>• Reduced oxidative stress.</li> </ul>	Saleem <i>et al.</i> , 2022
Fresh cut Melon	Glycerol (GL) Citric acid (CA)	Dipping	AV- 100% GL- 2% CA- 0.1%	RT- 4°C (6 d)	<ul style="list-style-type: none"> <li>• Control WL, TA, AA, TPC</li> <li>• Lowered yeast and mould count</li> <li>• Showed very small change in Ph (5.55-5.68).</li> </ul>	Low & Chong, 2022

MD2 Pineapple (Ananas comosus)	NA	Dipping	AV- AL- (Each)	RT- 5°C (16 d) RH- 85%	<ul style="list-style-type: none"> <li>• <b>AL</b> showed effective color than control and <b>AV</b> treatment,</li> <li>• Extended shelf life,</li> <li>• Improved adhesion,</li> <li>• No significant changes in firmness in between coated and control treatment.</li> </ul>	Yong <i>et al.</i> , 2022
Strawberry (Fragiaananassa)	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%	<ul style="list-style-type: none"> <li>• Reduced decay rates, water vapour loss,</li> <li>• AV extended storage life up to 15days</li> <li>• Maintained antimicrobial properties.</li> </ul>	Pinzon <i>et al.</i> , 2020
-	Basil essential oil (BO)	Dipping	AV- BO-500 $\mu$ L L <sup>-1</sup> & 1000 $\mu$ L L <sup>-1</sup>	RT- 4°C (12 d) RH- 85%	<ul style="list-style-type: none"> <li>• Reduced respiration rate,</li> <li>• Decreases WL,</li> <li>• Controlled TA, flavor&amp;color</li> </ul>	Mohammadi <i>et al.</i> , 2021
-	Chitosan Sodium alginate	Dipping	AV- CTS- 2% AL- 2% (Each)	RT- 5-7°C (12 d) RH- 50- 60%	<ul style="list-style-type: none"> <li>• <b>AV</b> treatment preserve color, firmness, TA, TPC, AA, antioxidant activity &amp; reduced WL, antimicrobial, and antifungal properties.</li> <li>• AV &amp;CTS showed lowest decay indices.</li> </ul>	Qamar <i>et al.</i> , 2018
-	Sodium alginate	Electro spraying	AL-2%	RT- 7.5°C (13 d) RH- 90%	<ul style="list-style-type: none"> <li>• Raises transfer efficiency.</li> <li>• Provide uniform coating.</li> <li>• Maintain moisture loss, browning, extend storage time.</li> </ul>	Peretto <i>et al.</i> , 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 <i>et al.</i> , 2021

Apricot ( <i>Prunus armeniaca</i> )	Basil seed mucilage (BSM)	Dipping	AV- 30% BSM- 0.1% (Alone or combination)	RT- 2°C (28 d) RH- 85- 90%	<ul style="list-style-type: none"> <li>• <b>AV+BSM</b> treatment retard ethylene production, maintained firmness,</li> <li>• BSM preserved TA &amp; TPC, improve TSS, antioxidant activity, appearance.</li> </ul>	Nourozi& Sayyari, 2020
Peach	Chitosan	Dipping	AV-30% CTS-1.5%	RT- 3°C (36 d) RH- 85- 90%	<ul style="list-style-type: none"> <li>• showed best result of maintaining firmness, color, TSS, TA, TPC, antioxidant activity.</li> </ul>	Aboryiaet <i>al.</i> , 2022
Fresh cut Kiwi ( <i>Actinidia deliciosa</i> )	Hydroxypropyl cellulose (HPMC) Lemongrass oil	Dipping	AV-40% HPMC- 0.1% LEO- 1%  AV+HPMC AV+LEO	RT- 4°C RH- 90%	<ul style="list-style-type: none"> <li>• <b>AV&amp;HPMC</b>-based edible coatings elongated shelf life, preserving quality</li> <li>• <b>LEO</b> and <b>AV</b> altered taste.</li> <li>• <b>AV</b> with antioxidants and gelling agents proved most effective.</li> </ul>	Passafiume <i>et al.</i> , 2020
Litchi ( <i>Litchi chinensis</i> )	NA	Dipping	AV- 50%	RT- 20°C (8 d) RH- 90%	<ul style="list-style-type: none"> <li>• Reduce WL, MDA content, browning index,</li> <li>• Showed higher anthocyanin content, TPC prevent water loss, cell damage,</li> <li>• Acts as a good barrier in products.</li> </ul>	Ali <i>et al.</i> , 2019
Table Grapes ( <i>Vitis vinifera</i> L.)	Chitosan	Dipping	AV- 33% CTS- 3% (applied before harvesting)	RT- 4°C	<ul style="list-style-type: none"> <li>• Great effect on maintaining weight loss, TSS, TA, PH during storage time.</li> <li>• Maintain antioxidant activity, TPC, POD, vitamin C &amp; anthocyanin content.</li> </ul>	Nia <i>et al.</i> , 2021
Pomegranate arils ( <i>Punica granatum</i> )	Cinnamon oil (CO) Rosehip oil (RO)	Dipping	AV- 10% CO- 0.25% (Combined) RO- (0.25%,	RT- 5°C (15 d) RH- 95%	<ul style="list-style-type: none"> <li>• <b>AV+RO</b> delayed ethylene production</li> <li>• <b>AV+CO</b> significantly reduced microbial load &amp; maintained AA content</li> </ul>	Singh <i>et al.</i> , 2022

			0.50%)			
Tomato ( <i>Solanum lycopersicum</i> L.)	Sage oil (SO)	Dipping	AV- 10% SO-0.1%	RT- 11°C (14 d)  RH- 90%	<ul style="list-style-type: none"> <li>• Decrease ripening, WL TA, color</li> <li>• Maintained the quality of product</li> </ul>	Tzortzakiset <i>et al.</i> , 2019
–	Chitosan	Dipping	AV-1%, 2% CTS-1%, 2%	RT- 4°C (6weeks)	<ul style="list-style-type: none"> <li>• AV (1%) with AL (1%) preserved lycopene content, TA, AA, expanded shelf life up to 42days, highest TSS, antioxidant activity.</li> </ul>	Khatri <i>et al.</i> , 2020
Cucumber ( <i>Cucumis sativus</i> )	Carboxy-methyl cellulose (CMS)	Dipping	AV- 30% CMS- 1%	RT- 15°C (20 d) RH- 86%	<ul style="list-style-type: none"> <li>• Maintain color, firmness, WL, TSS, &amp; decreased fungal growth</li> </ul>	Sarker <i>et al.</i> , 2021
Fresh cut apple	Ferulic acid (FA) Sodium alginate	Dipping	AV- 40% AL- 1.25% FA- 1%	RT- 5°C (7 d) RH- 50%	<ul style="list-style-type: none"> <li>• <b>AV+FA, AL, AL+FA</b> showed less WL, no changes in texture, PH (3.9) during storage, <b>FA, AV</b> reduce browning,</li> <li>• <b>FA+AL</b> decreases microbial activity of <i>L. monocytogenes</i> pathogen, preserve TPC, antioxidant activities &amp; extend shelf life.</li> </ul>	Nicolau- Lapena <i>et al.</i> , 2021
Rambutan	NA	Spraying	AV-10%	RT- 10°C (10d)	<ul style="list-style-type: none"> <li>• Maintain freshness, peel color, texture, reduced respiration rate.</li> </ul>	Darmawati <i>et al.</i> , 2019

Papaya ( <i>Carica papaya</i> )	Sodium alginate Thyme oil (THO) Oregano essential oil (OEO)	Dipping	AL-2% THO-1% OEO-1%	RT- 4°C (12 d)	<ul style="list-style-type: none"> <li>Improved WL, decreased respiration rate, showed less changes in Ph, maintained taste &amp; aroma,</li> <li>THO &amp; OEO treatment slowdown microbial activity &amp; rheological properties.</li> </ul>	Tabassum & Khan, 2020
–	NA	Dipping	AV-50%	RT- 28°C (15 d) RH- 68-70%	<ul style="list-style-type: none"> <li>Observed highest TPC at 9<sup>th</sup> days, flavonoid content after 15days, highest Ph (6.04) but decreases as the end of storage period</li> <li>Maintained WL, firmness, ripening, and protection from pathogens.</li> </ul>	Mendy <i>et al.</i> , 2019
–	NA	Dipping	-	RT- 25°C (12 d) RH- 80-85%	<ul style="list-style-type: none"> <li>Slowdown color development</li> <li>Preserved WL (11.7%), moisture content (89.9%) up to storage</li> <li>Produce less TSS, TA</li> <li>Maintained yield quality &amp; extended storage life.</li> </ul>	Parven <i>et al.</i> , 2020
–	Calcium chloride Sodium alginate	Dipping	AV-30% AL-1.5% CaCl <sub>2</sub> -5%	RT- 5°C (12d) RH- 90%	<ul style="list-style-type: none"> <li>AV delayed color loss and ripening, conserved stiffness</li> <li>AL provides oxygen barrier, reduces respiration rate, maintained firmness.</li> </ul>	Farina <i>et al.</i> , 2020
Sapodilla ( <i>Manilkara zapota</i> )	Fagoniacretica (FC) plant extract	Dipping	AV- 50% & 100% FC- 1%	RT- 20°C (12 d) RH- 70-75%	<ul style="list-style-type: none"> <li>AV (100%) + FC Treatment controlled WL, firmness, decay indices, retard changes of TSS, maintained higher Ph, preserve AA</li> <li>AV (50%,100%) + FC sustained flavonoids, TPC</li> </ul>	Khaliq <i>et al.</i> , 2019
Green Chilli ( <i>Capsicum annum L.</i> )	NA	Dipping	AV- 50%	RT- 10°C (28 d) RH- 85-90%	<ul style="list-style-type: none"> <li>Minimizes the postharvest loss by extending the shelf life, respiration rate</li> <li>maintained POD, SOD, CAT activities and lowering water loss and diseases etc</li> </ul>	UI Hasan <i>et al.</i> , 2021

Green capsicum (Capsicum annuum)	Frankincense oil (FO)	Dipping	AV-66.7% AL-33.3% FO-6%	RT- 25°C (16 d) RH- 52%	<ul style="list-style-type: none"> <li>• Preserved UV barrier, water barrier properties, antifungal and antibacterial characteristics</li> <li>• maintains weight loss</li> <li>• improves sensory properties</li> </ul>	Salama & Aziz, 2021
Lotus roots slices (Nelumbo nucifera)	Ascorbic acid (AA)	Dipping	AV- 50% AA- 1%	RT- 20°C (5 d) RH- 85-90%	<ul style="list-style-type: none"> <li>• Slow down browning, microbial activity, H<sub>2</sub>O<sub>2</sub>, O<sub>2</sub> content</li> <li>• Maintained MDA, POD activities</li> <li>• Controlled CAT, SOD enzyme activities &amp; enhance the quality of products.</li> </ul>	Ali <i>et al.</i> , 2020
Button Mushroom (Agaricus bisporus)	Orange peel essential oil (Eos)	Dipping	AV- 50% Eos- 1500µL/L	RT- 4°C (16 d) RH- 90%	<ul style="list-style-type: none"> <li>• Delayed respiration rate</li> <li>• Restrained browning</li> <li>• Improved TSS, TPC</li> </ul>	Kumar <i>et al.</i> , 2023

[NA- Not Available, RT- Room temperature, RH- Relative humidity, AL- Alginate, AV- Aloe vera]

## 5. Process optimization and quality characterization

Process optimization plays a critical role in ensuring the effective application of edible coatings for preserving fruits and vegetables. Optimizing the coating process involves fine-tuning various factors such as coating material concentration, application methods, and storage conditions to achieve maximum efficacy. The goal is to enhance the coating's performance in maintaining the quality of produce while minimizing post-harvest losses and ensuring cost-effectiveness. Effective optimization not only increases the shelf life of coated products but also ensures the sustainability and scalability of the preservation method. Key factors to consider during the optimization process include the thickness of the coating, the drying time, and the environmental conditions during storage (e.g., temperature and relative humidity). Coating thickness significantly impacts the permeability of gases like oxygen and carbon dioxide, which in turn affects respiration rates and the ripening process of the produce. For example, an overly thick coating may lead to anaerobic respiration, causing off-flavors, while a coating that is too thin may fail to adequately prevent moisture loss.

Quality characterization is essential for evaluating the effectiveness of edible coatings. Several physical and chemical parameters are commonly assessed to determine the impact of coatings on fruit and vegetable quality, including appearance, weight loss, microbial activity, respiration rate, antioxidant capacity, and total soluble solids (TSS). These parameters offer insight into the physiological and biochemical changes that occur during storage

*Appearance*-Color is an important feature of fruit coating that gives us general idea about the quality of fruits. Its freshness and firmness showed consumers acceptancy, it plays an essential role for purchasing the item. Also peel color is primary factor to check its ripening/maturity, yield quality and storage time. During storage ethylene production increases that raises color of fruits which influences breakdown of chlorophyll, accumulation of anthocyanin, acceleration carotenoids. AV in a combination of alginate and chitosan helps to preserve color in strawberry (Qamar *et al.*, 2018) also AV with alginate and  $\text{CaCl}_2$  restrict papayas color (Farina *et al.*, 2020), AV with CMS improve color of cucumber (Sarker *et al.*, 2021), AV coating on color change of hog plum also documented (Shakil *et al.*, 2023).

*Respiration*-It is a metabolic process which causes breakdown of sugar, starch into small components like  $\text{H}_2\text{O}$ ,  $\text{CO}_2$ . It is very significant to preserve effectiveness of tissues and impart protection against degradation of postharvest loss. There are some extrinsic factor and intrinsic factor which affects respiration rate of plants such as relative humidity, temperature,

storage, stage of maturity & type etc. Among them temperature is an external factor which causes enzymatic reaction due to high respiration rate by increasing temperature. Temperature & Relative humidity both of them are inter related as they are inversely proportional causes moisture loss due to temp which represent weight loss in products. Also type & maturity stage influences rate of respiration as they have variations of different metabolic activity (Kandasamy, 2022). Rastegar & Atrash (2021) stated experimented taking 4 types of samples during 4 weeks storage period AL+AV & SP+AL showed less respiration rate results as this film have capability of replacing gases transportation, delaying respiration rate and enhance storage life. In pomegranate respiration rate ranges from  $9.04 \pm 1.06 \text{ nmol kg}^{-1}\text{S}^{-1}$  to  $15.20 \pm 1.10 \text{ nmol kg}^{-1}\text{S}^{-1}$  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 fruits quality make it undesirable. Also, less firmness and appearance properties affect market value. Weight loss occur due to outer peel or skin of fruits and vegetables. It means vapour pressure between fruits interior and air outside, moisture from fruit tends to escape through the peel that causes weight loss. Shakil *et al.*, 2023 reported that after using AV coating in hog plum it showed best result of maintain weight loss than paraffin waxes coated paper board packaging. Also, water loss ranges from 4.13% to 9.37% during storage period of 12days. Although AV film-maintained weight loss (7.4%) after storage period of 28days in green chilli (UI Hasan *et al.*, 2021), blueberry (Sempere-Ferre *et al.*, 2022) also alginate and aloe vera combined preserve weight loss in fresh cut apple (Nicolau-Lapena *et al.*, 2021). Others are mentioned in table.

*Microbial activity*-This indicated the presence or growth of microorganism 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 apple alginate-ferulic acid combination showed best result of reducing pathogen *L. monocytogenes* growth by  $2.3 \pm 0.4 \log \text{ CFU/g}$ . No improvement of reducing 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 growth of bacterial count but AV+AA significantly showed maximum retardation of microbial initiation by  $<6.0 \log \text{ CFU/g FW}$  (Ali *et al.*, 2019). AV has antimicrobial properties so it can reduce microorganism growth in blueberry (Sempere-Ferre *et al.*, 2022), AV with CMS combined film has effectiveness in

controlling microbes in cucumber (Sarker *et al.*, 2021), also combination of AV with LEO has the ability to inhibit or reduce microorganism in date (Alkaabi *et al.*, 2022).

*Antioxidant-Compounds* that helps 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 food to increase dietary content. Coating such as Gum Arabic (GA) & garlic extract (GE) helps to conserve bioactive compound like flavonoids, ascorbic acid & phenolics. AV (100%) with GA (10%) concentration resulted highest antioxidant  $814.6 \text{ mmol kg}^{-1}$  and GE (20%) with GA (10%)  $787.1 \text{ mmol kg}^{-1}$  showed less antioxidant activity but both concentration lower than control  $821.6 \text{ mmol kg}^{-1}$ . On the day 6 and 15 is showed decreasing of antioxidant & showed highest on day 3, 9, 12 during storage (Anjum *et al.*, 2020). In pomegranate arils, less changes of radical scavenging activity (RSA) in between control and treated samples. As the days passed RSA decreases 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. As CO elongated antioxidant activity and introduce better storage life and AV with CO & RO preserved phenolic compounds (Singh *et al.*, 2022).

*Total soluble solids & Titrable acidity*- It analysis concentration of sugar and other soluble components & ensures about fruit ripening and maturity stage. TA is used to determine acidity present in fruits. Aloe vera gel coated shown significantly higher TSS than control treatment & lower in acidity in green chilli (Ul Hasan *et al.*, 2021). Result of combined treatment after 15days of storage TSS gradually increases during storage time of 15days among them control showed 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).

*Shelf life*-It is critical factor for determining quality of food products. In guava combined treatment of GA with garlic extract showed maximum shelf life up to 13days and control showed minimum shelf life but lower than GA with AV treatment (Anjum *et al.*, 2020). In papaya aloe vera gel introduced maximum shelf life up to 14days while control showed minimum storage period 7days (Parven *et al.*, 2020). Combined treatment of AV (66.7%) alginate (33.3%) with FO (6%) showed its capability of maintaining storage life up to 16days

in green capsicum. Also, this treatment doesn't induce any in organoleptic alterations, maintained 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 (Ferina et al. 2020; Iolanda Nicolau-Lapeña et al., 2021; Passafiume et al., 2020; Shenbagam et al., 2023). 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 combination of aloe vera and sodium alginate as edible coatings offers a sustainable and effective solution for extending the shelf life of fruits and vegetables. Aloe vera's moisture retention, antioxidant, and antimicrobial properties, combined with the structural integrity and gas barrier capabilities of sodium alginate, provide a synergistic approach to maintaining the quality and freshness of produce. These coatings help reduce

post-harvest losses by minimizing weight loss, delaying ripening, and preventing microbial growth. Optimization of these coatings, through factors such as thickness, drying time, and the incorporation of additives like essential oils, can further enhance their efficacy. The use of natural, biodegradable materials like aloe vera and sodium alginate addresses the increasing demand for environmentally friendly and health-conscious food preservation methods. Additionally, these coatings have shown success in preserving key attributes like color, texture, and firmness, making them a viable alternative to synthetic packaging and chemical preservatives. Further research should focus on optimizing the coatings for commercial application, ensuring safety, and addressing consumer acceptance. The use of aloe vera and sodium alginate coatings presents a promising strategy for reducing food waste and supporting sustainable practices in the food industry.

**Data Availability-** All the data is included in the manuscript.

**Ethical Guidelines-** Ethics approval was not required for this research

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