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Exploring the role and potential of edible waxes in enhancing quality and shelf-life of vegetable crops: A comprehensive review

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Abstract

Vegetables can be negatively influenced by various factors such as insects, micro-organisms, and the conditions they are exposed during transportation and preservation. Post-harvest interventions for vegetables that utilize green technology have been shown to offer significant health benefits. The post-harvest application of edible coatingis a popular method that prolongs the shelf-life of perishable vegetables. Edible coatings have become a reliable and secure method for preserving vegetables due to their film-forming features, antibacterial properties, biodegradability, and other biochemical properties. These substances effectively prevent the passage of oxygen, carbon dioxide, moisture, and water vapor. This post-harvest method is popular for its safety, lack of toxicity, and has a positive impact on the environment. It effectively extends the shelf-life of fresh vegetable harvests. Edible coatings made from lipids have become increasingly significant in the modern food industry. Various types of waxes, such as carnauba wax, candelilla wax, Japan wax, urinary wax, rice bran wax, and sunflower wax, are utilized in the creation of edible coatings. Plant waxes derived from the cuticle of fresh vegetables possess the essential characteristics required for use in the formulation of edible coatings made from plant waxes. Waxes have proven to be highly effective in various industrial applications, ensuring the preservation of vegetables' quality and extending their shelf-life.

1. Introduction

The preservation of food is a significant challenge, particularly when it comes to horticultural commodities. The global community has widely acknowledged the issue and aims to achieve a 55% decrease in per capita global food waste at the trade and buyer levels by 2030 (Pashova, 2023). Food losses manifest through several mechanisms, encompassing both production-related factors and those arising within supply networks, including post-harvest losses. Fruits and vegetables are subjected to significant post-harvest loss due to their inherent perishability (Devi *et al.,* 2022). The popularity of chopped vegetables is increasing the growing preference for fresh andorganic food items, along with the demonstrated efficacy of lifestyle modifications. The food industry continues to face difficulties in sustaining the production of innovative food products for a prolonged period (Sharma *et al.,* 2019). To maintain a healthy diet, it is imperative to incorporate fruits and vegetables as fundamental components. One of the most important things to prevent post-harvest losses is to slow down the biochemical processes, including ethylene generation, softening, color change, respiration rate, acidity, and weight loss (Aranda-Ledesma *et al.,* 2022; Nayak *et al.,* 2019). However, as more people learn about the problems associated with plastics, their tastes have shifted. These issues include the widespread utilization of non-renewable resources, safety concerns, environmental contamination and accumulation. One possible solution to the problem of meeting the current demand is using edible films and coatings (Saji, 2020). Edible coatings and films have been used in the food industry for centuries; thus, this is not a new way to preserve food. Examples include waxed vegetables and the cellulose lining of meat casings. Edible wrappings have been a part of Chinese cuisine since at least the 12thcentury (Panchal *et al.,* 2022). The development and application of the waxing process for fruits and vegetables in a marketable setting began in 1922. The digestive system may break down an "edible coating," a thin layer of material that preserves food by blocking oxygen, foreign germs, moisture, andsolute movement (Bucio *et al.,* 2021).

Edible coatings incorporate a semi-permeable barrier to improve shelf-life by reducing gaseous exchange, oxidative free radical reactions, and respiration, along with the migration of moisture, solutes, and other physiological ailments (Sharma and Kotiyal, 2023).The edible coating could be generally categorized into four major groups; namely, vegetable protein, lipids, polysaccharides, wax, and agro-industrial residues (Figure 1). To diminish the losses and to extend the shelf-life of produce edible waxes can be found to be more effective for achieving the target. These edible coating waxes can be applied to produce from various methods, and the major categories of these are, dipping, spraying, and brushing (Figure 2). Edible coatings serve as a protective barrier contrary to humidity, ambient gases, water vapors, carbon dioxide, oxygen and micro-organisms (De Oliveira Filho *et*

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al., 2021). They help to reduce oxidation and respiration reaction rates in vegetable crops. Post-harvest management strategies employ edible coatings to preserve the nutritive value of crops effectively. Chettri *et al.* (2023) states that the use of an edible coating, consisting of lipids, proteins, and polysaccharides, also effectively mitigates physical alterations that occur throughout the preservation process. The primary function of an edible coating is to offer a barrier that separates respiration, range of functional properties, including acting as an antibacterial and antioxidant agent (Sharma *et al.,* 2023). These properties contribute in enhancing the overall quality and extending the shelf-life of fresh and minimally processed vegetables (Yousuf and Qadri, 2020). Vegetables apply edible coatings as a protective layer to their external surface, effectively encapsulating the stomata. This phenomenon reduces the rate of transpiration, thereby decelerating the weight-loss process. Multiple studies have provided evidence of this phenomenon in a diverse range of vegetables, such as radishes, potatoes, tomatoes, turnips, bell peppers, and others. Natural biomolecules known as edible coatings enhance the aesthetic appeal and extend the shelf-life of vegetables (Chettri *et al.,* 2023; Momin *et al.,* 2021).

Fresh produce now uses coating emulsions. Carnauba wax typically couples with a variety of components, including wax, shellac, beeswax, morpholine, and candelilla, to form these coatings. Wax or oil are the most common forms of incorporation for lipid components when it comes to coatings (Bucio *et al.,* 2021). While beeswax is a natural substance, petroleum is the source of paraffin and polyethylene wax. Carnauba, candelilla, and rice bran waxes are natural plant waxes; carnauba, candelilla, and rice bran waxes are natural plant waxes (Aranda-Ledesma *et al.,* 2022; Nayak *et al.,* 2019). By acting as barrier films to prevent the passage of gas and moisture, waxes improve the surface appearance of a variety of fruits and vegetables. Applying them as a thick coating form prevents consumption, but applying them in thin layers permits consumption (Devi *et al.,* 2022).

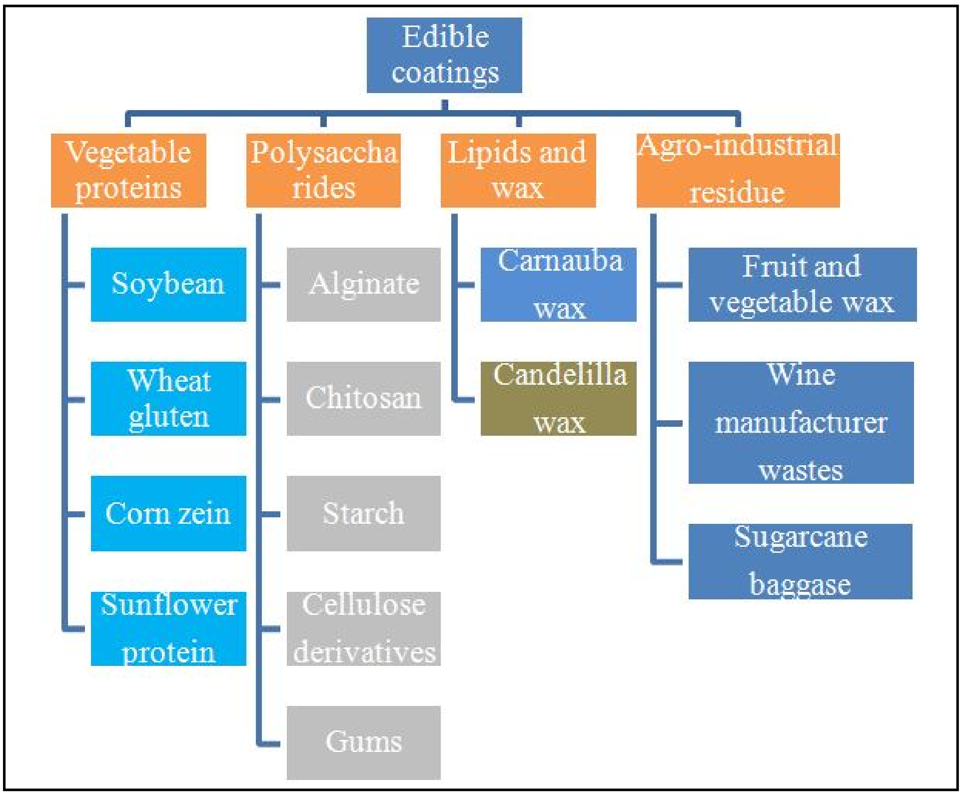

Figure 1: Classification of edible coating (Han 2005; Nur Hanani *et al.* 2014).

2. Edible waxes on different vegetables

Vegetables possess a chemical composition characterized by a higher proportion of readily accessible water, a lower content of carbohydrates (specifically sugars), and a pH level that tends to be close to neutral (Monteiro Fritz *et al.,* 2019). In vegetables, a significant amount of water and a pH level close to neutral create a micro-environment that is conducive to bacterial development. *Erwinia* sp. is a common bacterial species known for its role in causing spoilage or degradation in vegetables (Santos *et al.,* 2020). Microbiological contamination prevention, along with the regulation of gaseous exchange (namely oxygen and carbon dioxide) and moisture levels, facilitates the preservation of freshness, flavor, and aroma. This process also contributes to the maintenance of product quality (Radev, 2021). Enzymatic browning is a phenomenon that can be observed in certain vegetables throughout the processing and storage processes, mostly attributed to the presence of polyphenol oxidase. As a result of enzymatic browning, functional, nutritional, and organoleptic properties get worse. For example, the food gets softer, darker, and has a bad taste (Gutiérrez-Pacheco *et al.,* 2020). Enzymatic browning causes undesirable changes in food's sensory attributes, resulting in a decrease in its market value. Therefore, researchers have identified the aforementioned issue as a significant factor contributing to the economic losses incurred in the cultivation of various vegetables, including lettuce, potatoes, mushrooms, and others. Plasmids contain the substrates involved in enzymatic browning, primarily polyphenols, and the cytoplasm houses the enzymes responsible for this process (Saha *et al.,* 2016). During vegetable processing, tissue damage occurs, leading to the rupture of plastids. This rupture allows for the interaction between polyphenol oxidase and the substrates. Vegetables experience the widely documented phenomenon of enzymatic browning due to physiological or mechanical damage and microbial contamination during harvesting or storage (Li *et al.,* 2018). Edible wax coatings serve the purpose of preserving firmness and moisture, inhibiting oxidative browning, mitigating microbe development, and regulating respiration rate. The storage compartment has maintained controlled levels of relative humidity and temperature throughout the storage process (Mandal *et al.,* 2018). The use of edible wax coatings addresses the need for vegetables to maintain the quality and freshness. Edible wax coatings have been employed for a considerable period to preserve the quality and prolong the shelf-life of some types of fresh vegetables (Tahir *et al.,* 2019). Vegetables typically undergo a process when immersed or sprayed with various edible substances, which form a semi-permeable membrane on their surface. This membrane serves to inhibit respiration, regulate moisture retention, and fulfill other essential roles. Different researchers worked on edible wax coatings to prevent the spoilage of vegetables and improve their shelf-life (Garg *et al.,* 2021).

Table 1 represents the data related to edible wax coatings on different vegetables and their effects

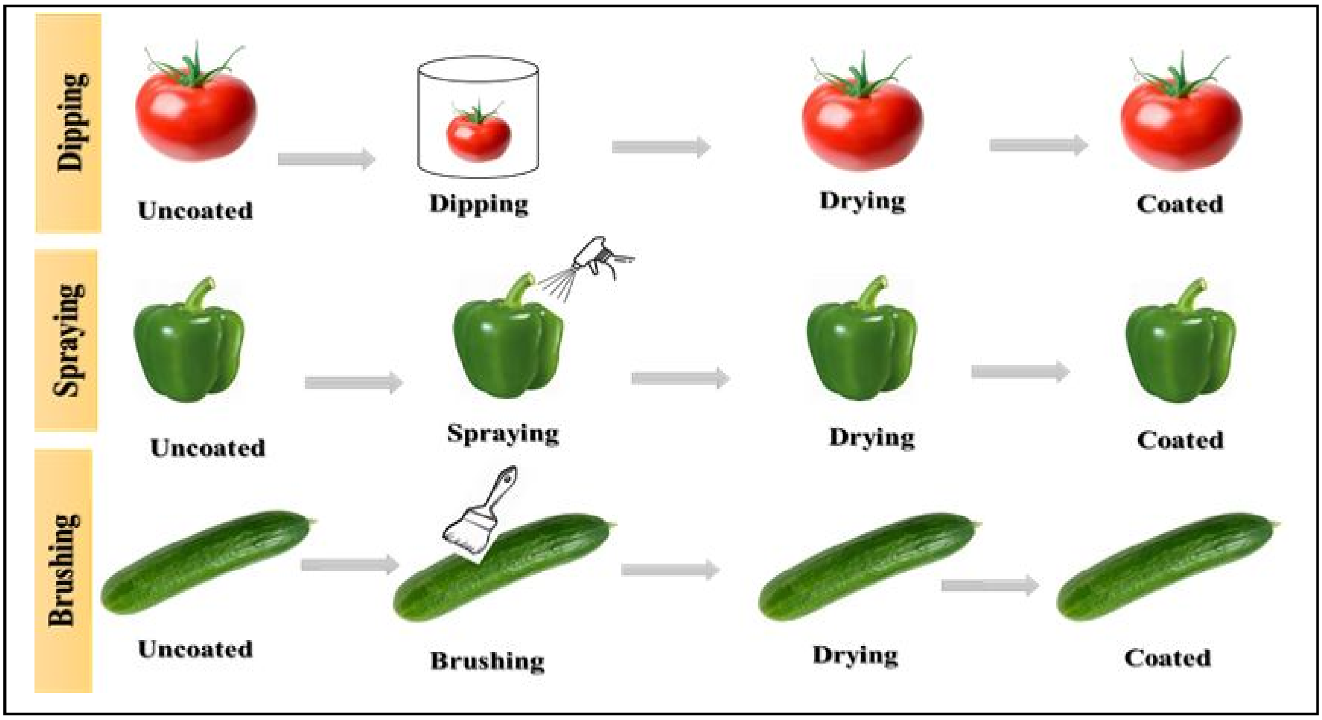

Figure 2: Pictorial representation of different application methods of edible coating employed on various vegetables.

2.1 Tomato

The application of a high-pressure processing technique is employed to create a carnauba wax nano-emulsion that can be utilized as an edible coating for tomatoes. A comparison was made between the attributes of nano-emulsion and conventional carnauba wax emulsion (CWM). In this study, we evaluated the postharvest quality of cv. 'Debora' tomatoes by applying two different coatings; namely, CWN and CWM, at concentrations of 9% and 18%. These coated tomatoes were then compared to uncoated tomatoes after a storage period of 15 days at a temperature of 23°C. Consumers preferred the tomatoes coated with the CWN in sensory evaluations, demonstrating the potential of the developed carnauba wax green nano-emulsion for post-harvest applications (Miranda *et al.,* 2022). The impact of various locally sourced edible coating materials; namely, bee wax (BW), shea butter (SB), and cassava starch (CS), on the physical and chemical characteristics of tomatoes during a storage period of 20 days at a temperature of 20°C and relative humidity ranging from 80 to 90%. Bee wax (BW) applied to tomatoes preserved their antioxidant activity, total phenolic content (TPC), organoleptic qualities, resistance to enzyme activities, slowed down the ripening process, stopped weight loss, made the tomatoes firmer, and extended the time they could be stored. Considering the physical and chemical qualities, the application of bee wax treatment presents a promising post-harvest approach to maintain the quality and extending the shelf-life of fresh tomatoes (Osae *et al.,* 2022). The use of rice bran wax (RBW) as a coating substrate is a promising approach to extend the shelf-life of products. An emulsion of RBW was prepared, with varying quantities employed to coat the tomatoes. It was observed that tomatoes coated with10% emulsion exhibited a longer shelf-life of 27 days in comparison to the control samples, which had a shelf-life of 18 days (Abhirami *et al.,* 2020). Tomato fruits coated with wax exhibited a delay in pigmentation, accompanied by favourable fruit firmness (Mandal *et al.,* 2018). Fruit coated with wax and chitosan (2%) during storage demonstrated a delayed ripening process. The fruit displayed a low ratio of total soluble solids (TSS) to acidity, and the wax-treated tomato fruit demonstrated a notable preservation of ascorbic acid. These fruits also show an extended shelf-life, lasting for a maximum of 26.33 days (Mandal *et al.,* 2018). In a case study conducted by Jafari *et al.* (2018) revealed that the edible coating of *Artemisia sieberi* and trehalose showed a positive increment in some of the visual and sensory attributes of tomato; namely, aroma, color, flavor, and texture. However, ten days after the storage of tomato coated with edible wax, optimal results have been recorded for appearance, firmness, and marketability, respectively.

2.2 Broccoli

Broccoli floret preserved with cellophane coating can help to improve weight, visual quality, and marketability. The application of a coating containing 0.4% tragacanth gum led to the desired levels of soluble solids content, as well as increased titratable acidity and improved organoleptic qualities broccoli can effectively be preserved *via* tragacanth gum coating used as a biomaterial to substitute synthetic cellophane film (Varasteh and Zamani, 2022).

2.3 Potato

Ghannam *et al.* (2021) investigated the shelf-life of potatoes by utilizing gum Arabic. The impact of applying edible film (GA), combined with $CaCl_2$ and glycerolas the base matrix, is lower microbial load, reduced weight loss, lower TSS, improved pH, and aprolonged shelf-life for potatoes. The coating treatments of Purple Majesty and Rio Grande Russet maintained better tuber quality. The F2, F3, and F7 coating preparations worked better than the others at reducing weight loss, keeping the shape, and improving the feel of Purple Majesty and Rio Grande Russet cultivars in F1, LRHSC. F2, and F3 coatings meaningfully delayed tuber sprouting at room temperature (Emragi *et al.,*2022).

2.4 Cucumber

Chitosan-OEO films were able to prevent the *in vitro* development of *A. alternata*; they were only able to limit the growth of *Escherichia coli* O157:H7, *Salmonella typhimurium*, fungi (isolated rotting cucumbers) and mesophilic bacteria. In addition, the infrared study of the chitosan-OEO-wax films showed shifts in the O-H and N-H absorption bands, which suggests that the components may have formed hydrogen bonds with one another. Chitosan and chitosan OEO were the utmost efficient antibacterial treatments, while wax and wax-OEO were the furthermost effective coatings to avoid weight loss in cucumbers after 15 days of storage at 10^0C. The most effective coatings were wax and wax-OEO (Gutiérrez-Pacheco *et al.,* 2020). Cucumbers were subjected to a 10% wax treatment and thereafter subjected to storage conditions at temperatures of 15, 20, 25, or 30°C, along with a RH (relative humidity) of 55%. The measurements of sample mass were obtained at 6 h intervals. The result of the study indicates that the combination of wax coating and minimum temperature was extremely successful in mitigating the moisture losses in cucumbers during simulated distribution. Following a storage period of 48 h, the cucumbers treated with wax exhibited a reduction in moisture loss of 45% compared to the control group stored at a temperature of 30°C. A positive interaction was seen between the application of the wax coating and the storage temperature, resulting in extended shelf-life for cucumbers (Gutiérrez-Pacheco *et al.,* 2020). The formulations comprise carboxymethyl guar gum, guar gum, potassium sorbate, glycerol, water, cinnamon oil, and an emulsifying ingredient. Various quality criteria were evaluated to evaluate the effects of the coating. The attributes assessed in this study encompassdecay loss, weight loss, ascorbic acid content, soluble solids, pH, juice content, titratable acidity, total phenolics, microbial activity evaluation, and antioxidant activity. The application of the coating resulted in a decrease in weight loss, decay loss, acidity, and total phenolics while also maintained antioxidant activity. Additionally, it led to a reduction in microbial infection, consequently extending the post-harvest storage span of cucumbers under ambient circumstances (Saha *et al.,* 2016).

2.5 Carrot

The influence of carboxymethyl cellulose/candelilla wax edible coating combined with ascorbic acid on carrots. Carrots that had been minimally processed (MPC) were covered in an emulsion of ascorbic acid and candelilla wax/carboxymethyl cellulose. Then, they were put in plastic boxes with cut polyethylene wrap and kept at 5^0C. It was concluded that the samples' horizontal cross-section took in more emulsion than their side surface. Scanning electron microscopy was used to look at the individual wax globules of the coating that were formed inside the damaged (by peeling) cortical cells. The coating boosted the MPC's resistance to water vapor, sped up respiration for a short time, lowered polyphenol oxidase activity, and stopped the development of "white blush". When the MPC was coated, it did not change its acidity, total phenolic content or structure. Overall, the edible coating and packaging can be a good way to keep slightly processed carrots tasting fresh for up to 21 days in cold storage. When carrots that have been slightly processed are treated with an emulsion of candelilla wax, ascorbic acid, and carboxymethyl cellulose, they retain more of their moisture (Kowalczyk *et al.,* 2020). The use of carnauba wax on carrots serves the objective of prolonging their freshness by delaying the decline in color, flavor, moisture, and firmness over an extended period. The carnauba wax, when diluted to a concentration of 5.3% wax level, demonstrated the highest sensory scores for flavor, body, and texture. The carnauba wax solution with a dilution level of 4.8% had the highest red color response (α-value) at both room temperature and low temperature. The hardness of carrots coated with carnauba wax exhibited an increase in force (measured in grams) throughout storage at both room temperature (26-32°C) and cold temperature (10°C). After 50 days of refrigerated storage and 35 days of room-temperature storage, the carnauba wax solution with a wax concentration of 5.3% demonstrated a minimum PLW (percentage of wax loss) of 3.24% and a maximum PLW of 3.82% (Singh, 2017).

2.6 Green chilies

To enhance the preservation of green chilies and to minimize preservation costs, a composite edible coating was applied to the chilies. This coating comprised of tween-80 (0.05%), glycerol (1%), gum Arabic (5%), and thyme oil (0.5%). A dipping method was used for coating, with three different dipping periods of 1, 3, and 5 min. The physicochemical properties of the coated and control chilies were assessed periodically during storage at room temperature (28 ± 2ºC). Characteristics were recorded amongst the control chilies and the chilies coated with varying dipping periods of 1-5 min. The coated green chilies exhibited a significant increase in the retention of total chlorophyll content, ascorbic acid, color, firmness, and improved organoleptic qualities. Through a 3 min dipping process, anamalgamated edible coating consisting of gum Arabic and thyme oil was applied, demonstrating its efficacy in maintaining the ideal physicochemical and organoleptic characteristics of green chilies for

12 days. In comparison, uncoated chilies exhibited a shorter shelf-life of six days when stored at room temperature (Valiathan and Athmaselvi, 2018).

2.7 Capsicum

Different carnauba wax emulsion dilutions (3.7-4.8%) were used to study capsicum shelf-life and quality. Flavor and texture scores reached 7.0-7.5 after 15 to 20 days at the ambient temperature and 30 to 35 days in refrigerated storage with carnauba wax emulsion (3.7 to 4.0%). Carnauba wax dilution caused a minimum physiological weight loss (Singh, 2017). The performance of three distinct biopolymers; namely pectin, gumarabic, and xanthan gum, when combined with candelilla wax (hydrophobic phase), jojoba oil (plasticizer), and a crude extract of polyphenols (bioactive chemicals). The capsicum underwent immersion treatment, thereafter stored at ambient temperature. The findings of the investigation revealed that there were significant changes in total soluble solids, weight loss, colour, appearance, pH, and stiffness. These changes were determined by the kinetic analysis. The fruit treated with an edible coating exhibited a notable disparity in weight loss when compared to the control treatment, which did not involve the use of an edible coating. Furthermore, fruits treated with an edible coating containing Arabic gum displayed a reduced level of deterioration. However, the visual appearance of the fruit treated with various edible coatings remained comparable. The application of a combination of biopolymers, jojoba oil, polyphenols, and candelilla wax in the development of edible and functional coatings has been found to greatly enhance the shelf-life of green bell peppers stored at a temperature of 25ºC, extending it for 10 days (Ochoa-Reyes *et al.,* 2013). Coating treatments were given to capsicum fruit by dipping them in aqueous solutions of aloe vera gel (4, 5, and 6%), gum Arabic (6, 9, and 12%) and cinnamon oil (0.5, 0.75, and 1%). Quality of capsicum fruit improved in all coating treatments. Results concluded that 12% gum Arabic coating exhibited significantly reduced membrane leakage, weight loss, chilling injury, and decay incidence with less increase in TSS, pH, and sugar percentage. Results showed that coating capsicum fruits with 12% gum Arabic can maintain the post-harvest storage quality of bell pepper fruit (Ullah *et al.,* 2017). Various coatings of *Aloe vera*, starlight wax emulsion, garlic, and mint leaf extract were applied to freshly harvested fruit kept at 10 ± 2ºC for storage. The coated fruit revealed lesser variations in various physicochemical characteristics like ascorbic acid, PLW, titratable acidity, phenols, TSS, sugars, and capsaicin content during storage. 50% and 25% starlight coating and 15% *Aloe vera* leaf extract were found to be the most effective treatments in maintaining the post harvest quality of capsicum fruits (Kumar *et al.,* 2019) as they restricted of metabolic activities and delayed senescence.

2.8 Pointed gourd

The application of potassium metabisulphite, sodium hypochlorite, and carnauba wax was tested on pointed gourd quality as well as physiological activities under cold storage (8-10°C and relative humidity 85%) for 15 days. Fruit treated with 500 mg/l KMS, 200 mg/l NaClO and 1:10 wax emulsion reduced respiration, physiological weight loss, a larger hue angle, and a lower chroma value for ten days. In T2 fruits, skin chlorophyll retention was double that of a 1:10 wax emulsion. NaClO, KMS, and carnauba wax can prolong the storage (Kumar *et al.,* 2009).

2.9 Beans

To increase post-harvest life, green beans (*Phaseolus vulgaris* L.) were coated with edible *Aloe vera* gel by immersing them in a 1:1 (50%); 1:3 (25%) aloe solution; or distilled water (0:1) for 5 min at room temperature. Regardless of the amount of Aloe gel used, samples stored at 5°C showed better colour retention, the least amount of weight loss, and higher visual quality than samples stored at 10°C. Soluble content was higher and weight loss was lower in the treated samples, electrolyte leakage was higher in non-treated products (Relter *et al.,* 2016).

2.10 Bitter gourd

Edible coatings, particularly chitosan and carnuba wax can be used as post-harvest treatments for enhancing the storage life of bitter gourd fruit under ambient storage conditions (temperatures of 27.4-32.3°C and 70-81% relative humidity). The 1.0% carnuba wax-coated bitter gourd fruits retained a higher sensory score of 6.67 during storage. Fruit treated with carnuba wax showed the least physiological weight loss, losing 4.61% of their weight by the end of the storage period. For as long as four days, the fruit treated with carnuba wax (0.50 and 1.0%) showed no signs of deterioration. The fruit revealed a disease reduction index of 83.98. On the second, fourth, and sixth days of storage, the amount of chlorophyll did not decrease, with 1.0% carnauba wax-coated fruits exhibiting the highest retention of chlorophyll a (9.67 mg/g), chlorophyll b (4.60 mg/g), and total chlorophyll (14.28 mg/g). Hence, it could be concluded that post-harvest application of carnauba wax has the potential to preserve quality attributes extend storage life of bitter gourd fruit (Bhattacharjee and Dhua, 2017).

2.11 Cauliflower

The tapioca-starch solution was used in three different concentrations (5, 10, and 20 g/l), and gelatine was added at the stable concentration (2.5 g/l). Results revealed that the PPO activity of edible-coated samples was found to be higher than the control.When compared to the other treatments, samples coated with a 2,0% tapioca starch had the lowest weight losses and browning rate. TSS of fresh-cut cauliflower stalks coated with tapioca starch at all doses was determined to be higher than that of the control. Hence, it could be concluded that the edible coating with tapioca starch increased TSS and decreased the weight loss (Kasim and Kasim, 2017).

2.12 Taro

Coating solutions with chitosan improve the microbial and chemical properties of coated taro. The improvement gets better as the chitosan percentage goes up, and it is best when the solution has 100% chitosan. The TSS, pH and firmness changed slightly during the storage period. A 100 % chitosan coating treatment extends fresh-cut taro's shelf-life by 20 days and improves its quality and acceptability. Chitosan coatings inhibited the growth of yeast, total-count bacteria and mould throughout the storage period and improved the sensory evaluation. Chitosan/starch coating solutions increase the shelf-life and enhance different properties of fresh-cut taro because chitosan behave as pseudoplastic (Aly *et al.,* 2017).

2.13 Sponge gourd

The results showed that chitosan at 0.5% and 1.0% were effective in reducing weight loss and respiration rate, preserving visual appearance, firmness and retaining the content of ascorbic acid and total phenolics, and delaying the increased polyphenol oxidase (PPO) activity. Moreover, 1.0% chitosan markedly suppressed peroxidase and phenylalanine ammonia-lyase activities and exhibited a low level of cellulose contents compared with 0.5% chitosan and the control. The use of chitosan effectively extended the shelf-life and retained the sponge gourd's post-harvest quality (Han *et al.*, 2014).

2.14 Lettuce

Three coating; namely, alginate, chitosan, and carrageenan could stop enzymatic browning by keeping the total phenolics content the same and lowering the activities of phenylalanine ammonolyses and polyphenol oxidase. These coatings also lowered the activities of phospholipase D and lipoxygenase, increased the activities of antioxidant enzymes (superoxide dismutase, peroxidase, catalase, ascorbate peroxidase) and decreased the amount of malondialdehyde. Furthermore, all coatings had a positive effect on the sensory properties of fresh-cut lettuces after 3 days of storage. Also, the chitosan coating improved the quality and best at stopping enzymes from turning it brown and repairing membrane oxidative damage lettuce. These results concluded that polysaccharide-based edible coatings helped to inhibit enzymatic browning, maintain quality, and postponed the senescence of fresh-cut lettuce (Li *et al.,* 2018).

2.15 Okra

Coatings made of guar gum and sodium chloride effectively slow down the deterioration of chlorophyll in okra when stored at 25°C. Throughout a 21-day storage period, these coatings consistently maintained chlorophyll levels, surpassing those treated with distilled water by a factor of 1.30 to 2.35. Utilizing gum coatings shows promise in preserving the nutritional value of okra pods while also mitigating microbial growth. The incorporation of gums in okra coating formulations demonstrates potential in delaying the ageing process of the vegetable (Sarpong *et al.,* 2020).

2.16 Brinjal

An edible coating derived from carnauba wax proves beneficial in prolonging the shelf-life and maintaining the quality of eggplant (*Solanum melongena* L.) fruits. Findings indicate improvements in commercial characteristics such as shine, quick drying, and decreased natural weight loss. The inclusion of additives like PEG, SA, and SDS in CW emulsion coating has the potential to prolong the shelf-life and boost the antioxidant properties of packaged eggplants when stored at room temperature for an extended period. Eggplants coated with CW containing PEG and SA exhibited decreased firmness, moisture content, and lightness, along with reduced physiological weight loss, indicating improved storage resilience. However, the total phenolic content (TPC) and antioxidant activity did not follow a consistent trend during storage for up to 12 days (Singh *et al.,* 2016).

Table 1: Different vegetables coated with wax and their effects

Vegetable	Coating materials	Effect on fruit	References
Solanum lycopersicum L. (Tomato)	Rice bran wax + polysorbate-80 + distilled water	Delay the ripening, avoid spoilage, decrease respiration rate, improve the quality of the fruit, and eco-friendly coating	Abhirami *et al.,* 2020
	Carnauba wax + oleic acid + ammonium hydroxide	Maintained respiratory rate, enhanced firmness, improved gloss, and color, preserve the quality, improved the sensory aspects of vegetable	Miranda *et al.,* 2022
	Bee wax + cassava starch + shea butter	Preserved the antioxidant activity, extended storage life improved physical and chemical properties	Osae *et al.,* 2022
	Carnauba wax + chitosan	Retained ascorbic acid, improved respiration rate, enhanced antioxidant activities, enhanced fruit longevity and consistent fruit quality	Mandal *et al.,* 2018
Brassica oleracea L. var. *italica* (Broccoli)	Tragacanth gum + distilled water + glycerol	Retained weight, maintained respiration rate, increased titratable acidity, improved organoleptic quality, maintained quality of broccoli, and improved shelf-life	Varasteh and Zamani, 2022
Solanum tuberosum L. (Potato)	Gum arabic + glycerol + calcium chloride	Improved respiration rate, reduced weight loss, increased tss, reduced microbial load, and environmentally friendly coating	Ghannam *et al.,* 2021
	Zein + alginate + potato starch + essential oil	Maintained better tuber quality, firmness, reduce weight loss, increase sensory and delayed tuber sprouting	Emragi *et al.,*2022
Cucumis sativus L. (Cucumber)	Chitosan + carnauba wax + oregano essential oil	Decreased microbial load, weight loss, improved antioxidant activity, effective for preservation and protection of cucumber	Gutiérrez-Pacheco *et al.,* 2020

	Shellac wax + carnauba wax	Decreased moisture loss, improved the respiration rate, maintained anti-oxidant activities, and improved storage temperature	Li *et al.,* 2018
	Guar gum + carboxy-methyl gum + glycerol + cinnamon essential oil + potassium sorbate + tween 80	Reduced weight loss, increased anti-oxidant activity, better firmness, retained shelf-life of cucumber, and retained microbial stability.	Saha *et al.,* 2016
Daucus carota L. (Carrot)	Candelilla wax + ascorbic acid + carboxymethyl + cellulose	Reduced weight loss, improved moisture retention, improved texture of vegeta-bles and avoid diseases	Kowalczyk *et al.,* 2020
	Carnauba wax + oleic acid	Retained ascorbic acid, improved color and glossiness, retained weight loss, improved storage for 35 days, and enhanced the quality	Singh, 2017
Capsicum annuum var. *longum* (Green chili)	Gum arabic + glycerol + thyme oil + tween 80	Retained ascorbic acid, improved acidity, improved the respiration rate, enhanced antioxidant activities, quality improvement, and shelf-life for 12 days	Valiathan and Athmaselvi, 2018
Solanum melongena L. (Brinjal)	Carnauba wax + sodium alginate + polyethylene glycol	Improved glossiness, decreased phys-iological weight loss, maintained anti-oxidant activities, improved shelf-life, and enhanced stability of fruit	Singh *et al.,* 2016
Capsicum annuum var. *grossum* (Capsicum)	Arabic gum + tar bush extract (act) + pectin gum + candelilla wax + xanthan gum	Improved appearance, reduced weight loss, enhanced firmness, improved total soluble solids, prolongedshelf-life, and improved the quality of bell pepper	Ochoa-Reyes *et al.,* 2013
	Aloe vera gel + mint leaf extract + garlic extract	Restricted of metabolic activities and delayed senescence	Kumar *et al.,* 2019
	Gum arabic + cinnamon oil + aloe vera gel	Reduced membrane leakage, weight loss, chilling injury, and decay incidence	Ullah *et al.,* 2017
	Gum arabic + chitosan + distilled water	Improved texture, maintained flavor, improved antioxidant activities, enhanced shelf-life for 30-35 days	Singh, 2017
Trichosanthes dioca (Pointed gourd)	Carnauba wax + potassium metabi-sulphite + sodium hypochlorite	Improved weight loss, improved res-piration rate, improved sugars, improved antioxidant activities, enhanced storage life, and improved quality parameter	Kumar *et al.,* 2009
Phaseolus vulgaris L. (Beans)	Aloe vera gel	Reduced weight loss, higher visual quality, and better color retention	Reuter *et al.,* 2016
Momordica charantia (Bitter gourd)	Carbuna wax + chitosan	Extended storage life and preserved other quality characteristics	Bhattacharjee and Dhua, 2017
Brassica oleracea var. *botrytis* (Cauliflower)	Tapioca-starch + gelatine	Lowered browning rate, reduce weight loss and increased tss	Kasim and Kasim, 2017
Colocasia esculenta L. *Schott* (Taro)	Chitosan	Enhanced microbial and chemical properties, improve quality and extend shelf-life by up to 20 days	Aly *et al.,* 2017
Luffa cylindrica (Sponge gourd)	Chitosan	Extended shelf-lifean retained postha-rvest quality	Han *et al.,* 2014
Lactuca sativa (Lettuce)	Alginate + chitosan + carrageenan	Inhibited enzymatic browning, main-tained quality and delayed senescence	Li *et al.,* 2020
Abelmoschus esculentus L. (Okra)	Guar gum + sodium chloride	Preserved chlorophyll content for 21 days, reducing the microbial load and delayed senescence	Sarpong *et al.,* 2020

3. Future aspects

The development of edible coatings for vegetable preservation represents a multi-faceted endeavour, necessitating further research and innovation to overcome existing challenges and capitalise on emerging opportunities. Future research directions could focus on identifying suitable biopolymers and examining their interactions with additives like plasticizers and emulsifiers. This exploration aims to refine coating compositions to improve food quality and prolong the shelf-life. Additionally, the selection of coating methods must be carefully considered to ensure their applicability across a variety of food products while preserving sensory attributes and nutritional integrity. Furthermore, to enhance functionality and efficacy, we need to mitigate the hygroscopic nature of plant-based biopolymers and explore novel compositions with other additives (Kumar *et al.,* 2023). In the quest for sustainable solutions, the recovery and valorization of biopolymers from food waste and by-products emerge as a promising avenue. By harnessing materials such as pectin, starch, proteins, cellulose and others from diverse sources, including fruits, vegetables, animals, and dairy products, it becomes possible to develop biodegradable and safe coatings for food products. This approach not only contributes to waste reduction but also aligns with sustainability goals, addressing environmental, economic, and social imperatives. Nunes *et al*. (2023) also state that combining plant-based materials with composite edible packaging is a good way to get around the problems and mechanical restrictions that come with single-use biopolymers. As the demand for healthier food options grows, active packaging systems and antimicrobial coatings derived from natural sources hold significant promise. These initiatives not only reduce food waste but also extend shelf-lifeand also contribute to plastic waste reduction and support circular economy principles. It is imperative to concentrate research efforts on creating formulations with superior moisture barrier capabilities and enhanced functionality. Additionally, there is a pressing need to innovate new techniques for applying coatings to enhance efficiency, adhesion, and durability. Throughout this process, prioritizing sensory attributes remains crucial, ensuring no trade-off between the quality and shelf-life of cut vegetables (Priya *et al.,* 2023). In conclusion, the future of edible coatings in vegetable preservation hinges on interdisciplinary collaboration, technological advancement, and a commitment to sustainability. By addressing current limitations and embracing innovative approaches, edible coatings have the potential to revolutionize the food industry, offering solutions that are both environmentally responsible and economically viable.

4. Conclusion

Edible coatings have multiple uses for a diverse selection of vegetables. They improve the external and internal characteristics of specific objects. Coatings are effective in preventing dryness and oxidation, which can lead to undesirable changes in color, flavor, and texture. Edible coatings are a diverse range of biopolymers that possess consumer-desired properties. These coatings are derived from polysaccharides, lipids, and proteins, either individually or in combination with other substances. The benefits of edible coatings are linked to the primary components found in their composition, including aroma substances, antimicrobial agents, antioxidants, vitamins, colouring substances, and probiotics. Various waxes, including candelilla wax, carnauba wax, Japanese wax, rice bran wax, urinary wax, and sunflower wax, are utilized in the manufacturing of edible coatings. These substances have characteristics and ought to be offered and utilized for preserving fresh vegetable produce. Waxescan enhance the micro-biological integrity of minimally processed vegetables, fruit, and other processed goods by effectively slowing down the ripening and senescence processes. Wax coating substances are derived from sustainable, edible sources, and in some cases, they are even produced from waste materials that present challenges for other industries in terms of disposal. The use of palatable coatings made from waxes in food technology is driven by their numerous advantages over synthetic films. These coatings can preserve the nutritional value and flavour of foods for an extended period during storage. Edible coatings made from lipids are commonly utilized in the field of food technology. When used on food products, they protect undesirable processes, ensuring the quality and safety of the products, and prolonging their shelf-life. Edible lipid-based coatings are environmentally friendly, as they are biodegradable and do not cause pollution. Additionally, these coatings are harmless and can be safely consumed along with the products. There is a growing demand for edible coatings that can be used in a wider range of food products to enhance their shelf-life and maintain their freshness. The use of wax edible coatings in the food industry ought to be highlighted as a groundbreaking solution that promotes environmentally friendly and sustainable production methods.

Authors' contributions

This work was carried out in collaboration among all the authors. Author PS and AG, contributed to the literature review, data collection, drafted sections related to topic and wrote the first draft of the manuscript. Authors VT and AK synthesized information, and contributed to the conceptual framework and assisted in the preparation of figures and tables. Authors AK, MK, SKY, provided expertise in this and contributing to the technical aspects of the review and assisted in reviewing and revising the manuscript for accuracy and scientific rigor. All the authors read and approved the final manuscript.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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