Journal of Advances in Biology & Biotechnology

Volume 27, Issue 11, Page 178-191, 2024; Article no.JABB.126037
ISSN: 2394-1081

Chitosan Based Edible Coatings: Enhancing Shelf Life and Quality in Fruits and Vegetables

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Authors' contributions

This work was carried out in collaboration between both authors. Author AM designed the study, wrote the protocol and wrote the first draft of the manuscript. Author GLPR managed the analyses of the study. Both authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jabb/2024/v27i111603

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/126037

Review Article

Received: 27/08/2024
Accepted: 29/10/2024
Published: 02/11/2024

ABSTRACT

Chitosan-based edible coatings have gained considerable attention as a sustainable solution for harvested fruits and vegetables which are highly prone to post harvest decay and quality deterioration during storage. Chitosan, derived from chitin exhibits biocompatibility, biodegradability and antimicrobial properties making it an ideal material for edible coatings. Edible coating act as effective barriers to moisture loss, gas exchange and microbial contamination thereby enhancing the quality and extending the shelf life of produce. Research has shown that chitosan coatings can significantly reduce respiration rates, inhibit enzymatic browning and preserve the sensory qualities of fruits and vegetables, contributing to a reduction in food waste and improved food security. The effectiveness of chitosan based coating is influenced by factors such as chitosan concentration, the addition of other natural additives and the methods of application. Studies have demonstrated that

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Cite as: *Aparna M., and Geetha Lekshmi P. R. 2024. "Chitosan Based Edible Coatings: Enhancing Shelf Life and Quality in Fruits and Vegetables". Journal of Advances in Biology & Biotechnology 27 (11):178-91. https://doi.org/10.9734/jabb/2024/v27i111603.*

chitosan coatings alone or in combination with essential oils or plant extracts effectively reduce weight loss, maintain firmness and prevent spoilage in horticultural perishables. Additionally, nano-encapsulated chitosan formulations have been explored for their enhanced protective effects offering more uniform coatings with superior barrier properties. The application of chitosan coatings is expected to evolve with the integration of nanotechnology, the development of functionalized chitosan molecules and the use of biocompatible additives. Chitosan coatings have been successfully applied commercially, such as in the preservation of perishables illustrating their potential as a sustainable solution with practical benefits for both scientific advancement and industrial application These innovations will further improve the efficacy of coatings by enhancing their moisture and gas barrier properties along with antimicrobial and antioxidant properties. Additionally, sustainability concerns are driving research into eco-friendly sources of edible coating and chitosan is a promising alternative to synthetic or chemical ingredients or fungicides. As the technology advances, chitosan based edible coatings are likely to have increased commercial adoption due to its sustainable and biodegradable nature. However, Chitosan-based coatings face challenges with solubility, application consistency, scalability, cost, allergen concerns, and varying regulatory standards.

Keywords: Chitosan; edible coating; fruits and vegetables; shelf life.

1. INTRODUCTION

Fruits and vegetables are essential constituents of a healthy diet and are considered as protective foods. India is the second largest producer of fruits and vegetables which has a production of 107.24 million MT of fruits and 204.84 million MT of vegetables from an area of 7.05 m ha and 11.35 m ha respectively (NHB, 2022). The major problem in fruits and vegetables is the postharvest losses due to their high perishability which is mainly due to high moisture content (80-90%) which leads to dehydration, mechanical injury, pathological breakdown, poor postharvest management practices, inadequate cold storage and processing facilities (Otoni et al., 2017). In India, postharvest loss in fruits and vegetables is estimated as 8 to 18% (APEDA, 2019). The perishable nature of harvested fruits and vegetables, along with the effect of environmental factors, storage conditions and transportation reduce the products quality and shelf life (Riseh et al., 2023). About half of the world's annual supply of tropical fruits is wasted making it more difficult to reach the Sustainable Development Goals which aims of eradicating hunger by 2030 even at expected alarming population rise of 9 billion by 2050 (FAO 2023)

Approximately 82.2 million tonnes of plastic packaging is used every year worldwide for packaging and most of this is put to one-time use and then discarded (Paidari et al., 2021). The edible coating is one of the best solutions to overcome the problem of postharvest loss and has the property to provide protection of fruits and vegetables against microbial contamination, reducing physiological activities thereby extending the shelf life of produce (Sarengaowa et al., 2022).

2. EDIBLE COATING

Edible coatings are thin layers of edible material that are applied to the product surface in addition to or as a replacement for natural waxy coatings. Their purpose is to provide a barrier to moisture, oxygen and solute movement for the food (Mitelut et al., 2021). Edible coatings is an unique approach to extend the shelf life of produce by providing an additional protective coating and also create modified atmosphere conditions around the produce (Liu et al., 2022).

The edible film enhances the mechanical and structural properties of fruits and vegetables. The ripening mainly starts with physiological process such as transpiration and respiration through microscopic pores on fruits and edible coating act as barriers, reducing the acceleration of these biochemical processes thereby enhancing the shelf life of fruits. It also act as a kind of packaging (Vargas et al., 2008). The coating materials are edible and will not leave any residues in the environment and are easily degraded (Galgano, 2015).

Edible coatings can affect the quality of coated fruits through various mechanisms which include structural reinforcement, controlled moisture transfer, controlled release of chemical agents, flavour compounds and antioxidants etc. The functionality of edible coatings can be enhanced by incorporating various antimicrobial agents,

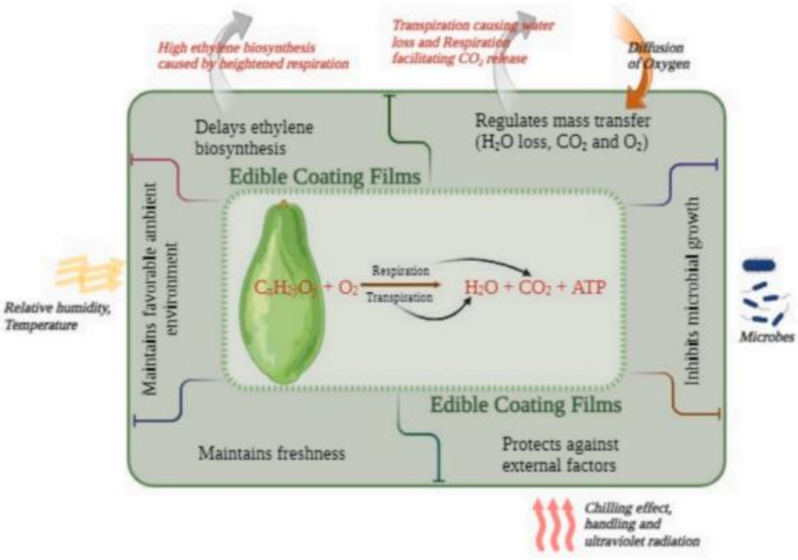

Fig. 1. Postharvest metabolism of an active edible coating (Olunusi et al., 2024)

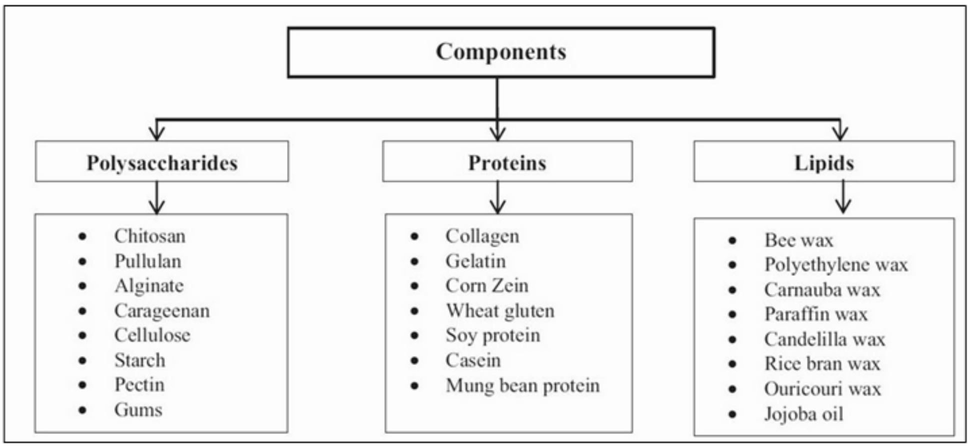

Fig. 2. Components of Edible Coating (Galgano, 2015)

antioxidants and functional ingredients such as minerals and vitamins. The advantages of edible coatings are mainly to reduce packaging waste, to extend the shelf life of the fresh and minimally processed product and to protect it from harmful environmental effect by maintaining the transfer of oxygen, carbon dioxide, moisture, aroma and taste compound (Riseh et al., 2023).

A schematic diagram for the postharvest metabolism mechanism present in fruits and vegetables are illustrated in Fig. 1.

2.1 Composition of Edible Coatings

A wide range of compounds are used in the formulation of edible coatings and their choice depends mainly on the target application (Vargas et al., 2008). Biopolymers like lipids, polysaccharide, protein and resin are most commonly used materials that can be used alone or in combination (Galgano, 2015).

3. CHITOSAN

Chitosan based coating has been used extensively due to its non-toxic, biodegradable and biocompatible properties. It is a basic amino polysaccharide present obtained from deacetylation of chitin, the second most abundant polysaccharide after cellulose. Chitosan has been categorized as Generally recognized as safe (GRAS) by Food and Drug

Administration (FDA). It has many benefits for agriculture, food and medicine because of its many functional properties. It can reduce the respiration rate of fruit by forming a coating on the fruit and adjusting the permeability of carbon dioxide and oxygen (Hu et al., 2023).

3.1 Diverse Application of Chitosan

Chitosan is used in agriculture as a natural, biodegradable pesticide and plant growth enhancer. It can protect crops from pests and diseases while promoting healthy growth. Chitosan is employed in food industry for its antimicrobial properties. It can extend the shelf life of perishable foods by inhibiting microbial growth by preventing spoilage. Chitosan is utilized in drug delivery systems, where it can encapsulate and release drugs in a controlled manner. It is also used in wound dressings, tissue engineering, and regenerative medicine. Chitosan's adsorption capacity makes it effective for removing heavy metals, dyes, and pollutants from wastewater, contributing to water purification and environmental sustainability. Chitosan is used in biotechnological applications, such as DNA purification, enzyme immobilization, and chromatography**.** Chitosan is found in various cosmetic products for its skin-firming and moisturizing properties.

3.2 Sources of Chitosan

Chitin production is mainly associated with food industries such as shrimp canning and fermentation process (Kou et al., 2021). The processing of crustacean shells mainly involves the removal of proteins and the dissolution of calcium carbonate and the chitin is deacetylated to form chitosan. On the other hand, chitosan-glucan complex are formed due to alkali treatment in fermentation process. The alkali removes protein and deacetylase chitin to chitosan-glucan complexes (Islam et al., 2023).

3.3 Structure of Chitosan

Chitosan, a partially deacetylated form of chitin, is a heteropolysaccharide composed of 2-amino-deoxy-β-D-glucopyranose and 2-acetamido-deoxy-β-D-glucopyranose (chitin) units (Khan et al., 2014). Its main characteristics are determined by the presence of three functional groups (primary -OH, secondary -OH, and -NH2) and its solubility in acidic pH. These reactive groups enable chitosan to prevent the growth of various bacteria and fungi (Hosseinnejad and Jafari, 2016).

3.4 Extraction Methods of Chitosan

Chitin from crustacean shell waste accounts for roughly half of the total weight of shellfish. In the processing of shellfish, parts such as heads, shells and tails are considered inedible. The uncontrolled disposal of this waste biomass poses environmental concerns. Given its abundance, crustacean shells are regarded as the preferred source for chitin extraction. Chitosan is typically obtained through two main methods: chemical and biological (Islam et al., 2023).

3.4.1 Chemical methods

Crustacean shells from various sources undergo preliminary steps, including washing, drying, and size reduction. The conventional chemical extraction method comprises three main stages: demineralization, deproteinization and decolorization. In the first step, the powdered shells are treated with an acid, typically HCl to eliminate minerals like calcium carbonate and calcium phosphate. Next, deproteinization is carried out using an alkaline treatment on the demineralized shells. If a colourless product is desired, a decolorization process is added, where pigments such as carotenoids are removed using acetone or organic solvent mixtures. The resulting chitin is then mixed with 40-50% NaOH. The degree of deacetylation of the resulting chitosan varies based on factors like reaction temperature, time, and alkali concentration. The alkali treatment hydrolyzes acetyl groups, converting N-acetyl-D-glucosamine units into D-glucosamine units with free NH_2 groups. Although the chemical method is preferred for commercial use due to its shorter processing time, it has drawbacks. The extracted proteins and minerals, which could serve as valuable supplements for human or animal consumption, are often damaged during the process. Additionally, this process is costly due to the need for effluent treatment to handle the acid and alkaline reagents. As a result, there is growing interest in biological extraction methods, which are safer and more cost-effective, though these are still primarily limited to laboratory-scale studies (Islam et al., 2023).

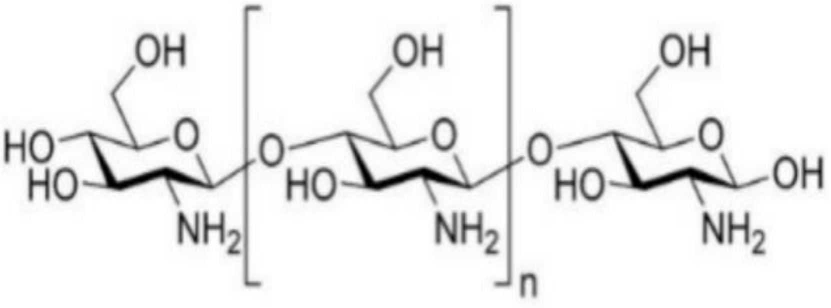

Fig. 3. Structure of Chitosan (Wang et al., 2024)

3.4.2 Biological methods

To avoid acidic and alkali treatment that could be a source of environmental problems, biological treatments offer an alternative way to extract chitosan from crustacean shell. Lactic Acid producing Bacteria have been used for demineralization of crustacean shell. In fact, the lactic acid produced by bacteria reacts with calcium carbonate component in the biomass resulting in the formation of calcium lactate, which is precipitated and removed by washing. For the deproteinisation, proteases producing bacteria will eliminate proteins. The step of decolouration is same for biological method *ie*. by using acetone or other organic solvent mixtures. Chitin obtained is then deacetylated to produce chitosan. Chitin acetyl groups are removed by chitin deacetylase enzyme produced by fungi or bacteria. This method has got several advantages over chemical method as it is environmentally safe and low cost because of the absence of effluents. Also, solubilized proteins and minerals which are obtained after the steps involved in the extraction procedure, can be used for human and animal nutrition (Kozma et al., 2022)

3.5 Essential Properties of Chitosan Coatings

3.5.1 Barrier properties

Chitosan films or coatings help reduce weight loss in fruits and vegetables by serving as a barrier to moisture loss. Additionally, edible coatings enhance texture, improve product appearance, and extend shelf life by forming semi-permeable barriers that control the flow of gases like oxygen and carbon dioxide, and moisture (Jafarzadeh et al., 2021). Chitosan is considered a promising coating material (Fig. 3) due to the following properties:

1. **Film-Forming Ability**: Chitosan can be transformed into thin films, coatings, or composites, which function as an effective barrier layer. These films offer strong resistance to moisture because of their dense structure.
2. **Hydrophilic/Hydrophobic Balance**: Chitosan's amphiphilic nature allows it to interact with both water and nonpolar substances. Its moisture resistance can be enhanced by modifying its chemical structure through acetylation or by blending it with hydrophobic polymers.

Chitosan films have proven effective at preventing the passage of gases, such as oxygen and carbon dioxide, in addition to moisture. This makes them suitable for extending the shelf life of perishable goods. Oxygen exposure can accelerate the deterioration of certain packaged fruits and vegetables, leading to nutrient loss, colour changes, and off-flavors (Lee et al., 2015). Furthermore, oxygen influences the respiration rate and ethylene production in these products.

Ethylene, known as the "ripening hormone," plays a crucial role in regulating plant processes like growth, ripening, and senescence. Controlling ethylene during storage can significantly extend the shelf life of fruits and vegetables, as increased ethylene levels lead to ripening, softening and degradation of chlorophyll eventually spoiling the produce (Kaewklin et al., 2018). By coating fruits with semi-permeable materials, such as chitosan, the availability of oxygen for respiration can be reduced, while carbon dioxide levels are increased, slowing down physiological processes and extending shelf life.

Chitosan coatings are particularly effective in inhibiting ethylene's impact (Yadav et al., 2022). They can form a barrier that prevents ethylene gas penetration, slowing the ripening process and prolonging the shelf life of fruits and vegetables. Chitosan may also adsorb or react with ethylene gas, capturing it and lowering its concentration in the surrounding environment, though this is not a direct inhibition of ethylene production.

3.5.2 Antimicrobial properties

With the increasing demand for fresh fruits and vegetables, it has become essential to extend their shelf life to maintain quality and reduce losses. One effective approach to achieve this is through the application of antimicrobial active packaging systems, which are infused with antimicrobial agents to prevent spoilage and control microbial growth.

Chitosan has been shown to exhibit significant antibacterial activity against a wide range of bacteria. The antibacterial properties and mechanism of action of acid-soluble chitosan have been attributed to factors such as membrane disruption, cell lysis, abnormal osmotic pressure, and the formation of a protective chitosan coating around bacterial cells. This has been demonstrated through various tests, including cell membrane integrity assessments, outer membrane permeability assays, and transmission electron microscopy observations. Furthermore, the biofilm biomass was significantly reduced after treatment with acid-soluble chitosan, highlighting the importance of biofilm formation in the antibacterial mechanism of chitosan (Guarnieri et al., 2022).

Chitosan exhibits antimicrobial activity against a variety of microorganisms, including Gram-positive and Gram-negative bacteria, fungi, and yeast. The antimicrobial efficacy of chitosan is explained by several mechanisms, with the most widely accepted being electrostatic interactions between chitosan and microorganisms (Sahariah and Masson, 2017). At low pH levels, there is a strong electrostatic interaction between the protonated amino (-NH2) groups of chitosan and the anionic carboxyl and phosphate groups on the bacterial cell surface. These interactions alter the permeability of the bacterial cell membrane, disrupting gas exchange between the cell's interior and exterior environments. Additionally, the rupture of the membrane leads to cellular dysfunction and the release of intracellular components (Romanazzi et al., 2018).

The primary factor influencing chitosan's antimicrobial activity is the presence, density, and location of cationic charges within its polymer structure. Furthermore, the antimicrobial properties of chitosan are also closely related to its molecular weight (MW) and degree of acetylation (DA) (Yang et al., 2023).

3.6 Methods of Application of Chitosan Coating

There are different application methods of edible coating which include spraying, dipping and foaming and dripping method.

Fig. 4. Physiological properties of chitosan (Wang et al., 2024)

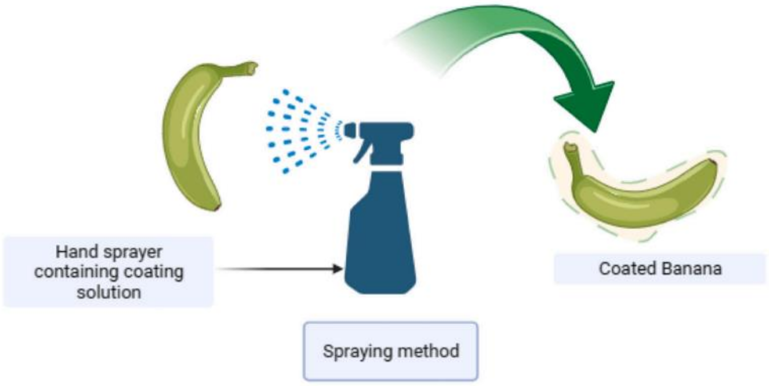

Fig. 5. Application of edible coating by spraying method (Galgano, 2015)

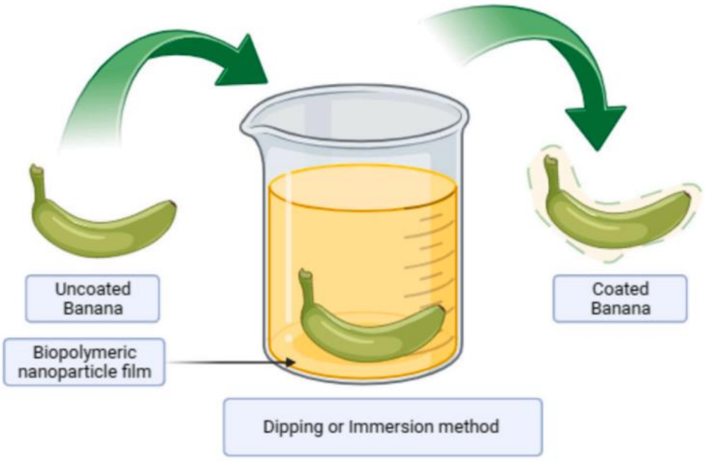

Fig. 6. Application of edible coating by dipping/immersion method (Olunusi et al., 2024)

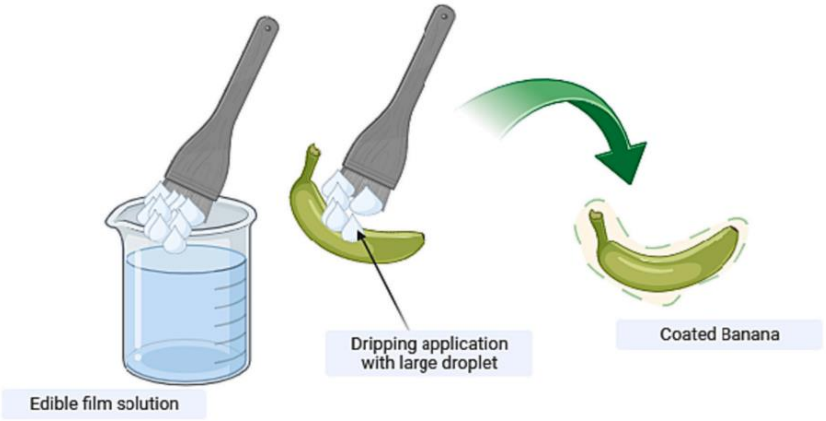

Fig. 7. Application of edible coating by foaming and dripping method (Olunusi et al., 2024)

3.6.1 Spraying

The spraying technique is commonly employed in large-scale industries because of its cost-efficiency and the high-quality results it delivers. This method ensures a uniform coating solution while allowing precise control over the temperature and thickness of the layers. Additionally, both the temperature and drying time during the spraying process influence the final quality of the coating (Andrade et al., 2012).

3.6.2 Dipping

This method is used to apply coatings on fruits, vegetables, meat, and other food products (Lu et al., 2010). In this process, the food items are immersed in a prepared solution to coat their surfaces. The key characteristics of the coating solution, such as thickness, density, and mechanical strength, are crucial for effective food product packaging (Adiletta et al., 2021).

3.6.3 Foaming and dripping methods

The dripping method applies a direct coating to the fruit surfaces using brushes in an attempt to extend the shelf life mainly for fruits like bananas. Here, edible films is delivered in the form of droplet with the help of a pressure emitter (Lam and Thang, 2013). They are combined with a foaming agent before compressed air is shot into the applicator air tank using this method, which is the most economical for coating applications (Guerra et al., 2024). Constant agitation is done for uniform distribution and to break up the froth (Kinnunen-Raudaskoski et al., 2017, Prasad et al., 2018). However uneven distribution of edible coating is one of the limitation of this method (Krzan, 2013).

3.7 Effect of Chitosan Coating on Fruits and Vegetables

Aerobic respiration is essential for harvested fruits and vegetables, as stored nutrients are utilized as substrates for respiration. As these nutrients decrease, the nutritional and commercial value of the produce diminishes accordingly. Controlling the respiration rate effectively can help extend the shelf life of postharvest fruits and vegetables (Perdones et al., 2012). The primary causes of weight loss in harvested fruits and vegetables include transpiration and the consumption of substrates for respiration. Approximately 80% of total weight loss is attributed to water loss, which affects the texture of fruits and vegetables, causing them to soften and lose their crispness (Velickova et al., 2013). When fruits and vegetables are coated with chitosan, more water is retained within the tissue, thereby increasing their commercial value (Bhan et al., 2022).

Firmness is a key sensory attribute of fresh fruits and vegetables. During storage, firmness tends to decrease due to water evaporation, pectin degradation, and nutrient depletion (Qi et al., 2011). Chitosan coatings help reduce transpiration, allowing more water to be retained, which in turn maintains higher cell turgor and results in greater firmness (Xiao et al., 2011).

Fruit browning is mainly caused by the enzymatic oxidation of phenolic compounds to quinones, a process mediated by polyphenol oxidase (PPO), which significantly reduces consumer acceptance and leads to over 50% of fruit losses. Numerous studies have shown that chitosan-based coatings can inhibit PPO activity in various fruits, including strawberries, sweet cherries, cherimoya, loquat, longan, guava, grapes, apples, mangoes, pistachios, lemons, and pineapples (Molamohammadi et al., 2020). This reduction in enzymatic browning is likely due to the lower availability of O_2 inside the fruit, which is required to initiate browning reactions (Li et al., 2020).

Banana fruits coated with various treatments, including chitosan, a combination of chitosan and gibberellic acid, Jojoba coatings, $CaCl_2$ and glycerol. They found that a 1.5% chitosan coating, as well as a 1.5% chitosan + GA_3 (100 ppm) combination, significantly delayed weight loss (6.20 ± 0.36), decay percentage (10.3%), total soluble solids (14.0%), pH (5.04 ± 0.06), titratable acidity, sugar accumulation, and pigment degradation. Moreover, these treatments resulted in a higher ascorbic acid content (26.2 mg/100 g) compared to uncoated fruits (14.9 mg/100 g) and extended the shelf life of the bananas to 17 days (Gol and Rao, 2011).

Suseno et al., 2014 investigated the effect of chitosan on Cavendish bananas stored at room temperature (30 ± 2°C) and found that a 2% concentration of chitosan was the most effective coating for reducing weight loss (30%) and vitamin C degradation (11%), while also maintaining desirable sensory attributes over a 7-day storage period. Similarly, Lustriane et al., 2018 studied the impact of chitosan and chitosan nanoparticles on the postharvest quality of bananas and observed that chitosan nanoparticles extended the shelf life and maintained the quality of bananas stored at ambient temperature (25 ± 1°C) for 15 days. Esyanti et al., 2019 reported that Cavendish bananas coated with 0.2% chitosan nanoparticles exhibited slower skin discoloration by 2-3 days compared to the control at 22 ± 1°C.

Chitosan edible coatings enriched with citrus limon peel extracts and *Ocimum tenuiflorum* leaf extracts on banana shelf life was investigated (Deb Majumder and Ganguly, 2020) at ambient temperature (30 ± 5°C, relative humidity 75 ± 5%) (Prashanth et al.,2022). A combination of 2% chitosan, 2% citrus limon peel extract, and 2% *Ocimum tenuiflorum* leaf extract significantly delayed weight loss (4.9 ± 0.19%), preserved ascorbic acid levels (30 mg/100g), and exhibited high antioxidant activity (70.08 ± 0.4%) with extended storage life of 16 days. Ahing and Wid, 2022 also studied the effects of acid-soluble chitosan on banana shelf life, and reported that 2% chitosan effectively maintained quality, with the lowest weight loss (22.6%) over a 12-day storage period.

Chien et al., 2007 evaluated the effects of chitosan coatings on the quality and shelf life of sliced mangoes stored at 6°C indicated that chitosan coatings reduced water loss (10.27%), maintained sensory quality, increased soluble solid content, titratable acidity and ascorbic acid levels, and inhibited microbial growth for up to 7 days. Jitareerat et al., 2007 examined The chitosan at 1.5% and 2.0% concentration was found effective controlling anthracnose in mango caused by *Colletotrichum gloeosporioides*. Zhu et al., 2008 explored the effects of chitosan on the postharvest quality of mango (cv. Tainong) stored at 15°C and 85–90% relative humidity and found that 2% chitosan reduced weight loss (49.8%) and disease incidence (71.3%) compared to control samples. The impact of *Aloe vera* gel, chitosan, and calcium chloride ($CaCl_2$) on mango shelf life stored at ambient temperature (25 ± 2°C, 80 ± 5% relative humidity) was assessed and the Aloe-chitosan coatings significantly decreased weight loss (30.4%) and ascorbic acid degradation over 21 days of storage Kumar et al., 2021 reported that chitosan-pullulan composite (50:50) edible coatings, enriched with pomegranate peel extract in mango, reduced physiological weight loss, maintained total soluble solids (TSS), acidity, and pH, and retained freshness, colour, taste, and texture for up to 18 days under cold storage conditions (4°C). Parvin et al., 2023 further examined chitosan's impact on mango storage, finding that 1000 ppm chitosan solution, combined with refrigeration (4°C) and zip-bag packaging, reduced weight loss by up to 65% over 45 days.

Bautista-Banos et al., 2003 investigated the effects of chitosan and plant extracts (custard apple leaves, papaya leaves, and papaya seeds) on *Colletotrichum gloeosporioides* growth, anthracnose levels, and papaya fruit quality. The results showed that 2.5% chitosan combined with plant extracts had a fungistatic effect, while 2.0% and 3.0% chitosan had fungicidal effects. The papaya fruits treated with 3% chitosan showed reduced physicochemical processes and decay, maintaining higher sensory quality during both ambient (28 ± 1°C) and cold storage (12 ± 1°C), with a shelf life of 9 and 23 days, respectively (Bhanushree et al. 2018).Escamilla-García et al., 2018 assessed the effects of chitosan and oxidized starch on papaya shelf life, reporting that 3% chitosan, minimized physicochemical changes and decay, while retaining optimal pH (4.3 ± 0.2), titratable acidity (0.12% ± 0.01%), and soluble solids (12 ± 0.2 °Brix) over 15 days at 25 ± 1°C. A combination of 1% chitosan and 1.5% ascorbic acid was found effective in maintaining papaya quality, reducing total soluble solids (TSS) by 3.45% and titratable acidity by 12.70% over 16 days of storage (Zhou et al, 2022) Raju et al., 2023 demonstrated that a coating of chitosan combined with, *Aloe vera*, and ascorbic acid preserved quality parameters in papaya, including titratable acidity (0.670%), ascorbic acid content (67.12 mg/100g), and TSS: acid ratio (23.11%) during storage and transportation.

Nguyen et al., 2020 explored the effects of hot water treatment (50°C for 5 minutes) followed by a composite coating of 1.0% chitosan and 0.2% carrageenan on dragon fruit and reported that the coating effectively controlled disease through antioxidant defense responses and maintained overall quality for 30 days at 10°C. The effect of different concentrations of chitosan (2%, 3%, and 4%) on the postharvest quality of dragon fruit stored at ambient conditions was investigated and found that 4% chitosan extended shelf life (14 days) and minimized weight loss (1.56%) compared to untreated fruits, which had a shelf life of only 8 days (Prashanth et al., 2022).

Yang et al., 2022 assessed chitosan coatings enriched with turmeric and green tea extracts for postharvest strawberry preservation and reported that chitosan coatings containing turmeric extract inhibited *Botrytis cinerea* proliferation over 7 days at 20°C, while green tea extract extended the antioxidant properties of strawberries. Sucharitha et al., 2018 found that 0.25% chitosan was more effective than 0.5% in maintaining the physicochemical characteristics of tomatoes, extending shelf life to 30 days at 6°C whereas

2.5% chitosan delayed ripening and extended shelf life up to 30 days in tomato (Sree et al., 2020).

Tafi et al., 2023 studied the preservation of fresh cherry tomatoes coated with insect-based chitosan at 0.5% and 1% concentrations, stored at room temperature and in cold storage (4°C) for 30 days and reported that insect-based chitosan had comparable properties to commercial chitosan derived from crustaceans.

4. FUTURE TRENDS OF EDIBLE COATING WITH CHITOSAN

Recent research in this area has concentrated on developing innovative technologies that enable more efficient control over the properties and functionality of coatings. In pursuit of this goal, several new methodologies have been introduced, primarily focused on composite or multilayered systems. However, their application to food products remains limited (Vargas et al., 2008). A new generation of edible coatings is currently being developed, aiming to incorporate and regulate the release of active compounds through nanotechnological approaches such as nanoencapsulation and multilayer systems. Presently, nanotechnologies are also being utilized to improve the nutritional value of food through nanoscale additives, nutrients, and nanosized delivery systems for bioactive compounds (Bouwmeester et al., 2009).

The future of chitosan edible coating as a technique for extending the shelf life of fruits and vegetables is likely to see significant developments and trends that build upon current research and technology (Deb Majumder and Ganguly, 2020). Here are some potential future trends in this field (Gaspar and Braga, 2023). Antimicrobial nano-based edible coatings are sustainable as compared to synthetic packaging and significantly reduces food spoilage (Rout and Pradhan, 2024). The chitosan edible coatings have the potential to play a crucial role in addressing food preservation challenges, reducing food waste, and ensuring the availability of fresh and safe fruits and vegetables. The future of this technology will likely be marked by continuous innovation, sustainability efforts, and increased adoption in the food industry.

5. CONCLUSION

Edible coating technology offers a promising approach for preserving the quality of fresh produce. Non-active coatings modify the internal environment of fruits by limiting gas and water exchange, which in turn lowers respiration rates, slows colour changes, and helps to maintain firmness. However, active edible coatings, which incorporate additional components, are more effective for extending the shelf life of fruits than non-active coatings as they can form a physical barrier and actively inhibit the growth of pathogens preventing decay. Chitosan, in particular, is gaining attention as an edible coating due to its natural antimicrobial properties, environmental sustainability, abundance, and excellent film-forming capabilities compared to other common biopolymers. In light of global food security concerns and the growing need for sustainable food preservation solutions, chitosan edible coatings offer a valuable strategy for reducing food waste, improving food safety, and ensuring greater access to fresh, nutritious produce. Hence, chitosan coatings are poised to play an increasingly important role in extending the shelf life of fruits and vegetables through edible coating technology.

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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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