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Edible coatings for fresh produce: exploring chitosan, beeswax, and essential oils in green chillies and pointed gourd

Eshita Vivek Vidyarthi, Mannat Thakur, Ramanveer Kaur Khela and Swarup Roy*

Department of Food Technology and Nutrition, Lovely Professional University, Phagwara, Punjab 144411, India
* Corresponding author, E-mail: swaruproy2013@gmail.com

Abstract

In response to the rising global concerns over food sustainability and the pressing need to minimize waste, finding efficient, eco-friendly preservation techniques have become increasingly urgent to prevent environmental deterioration and ensure food security. The present study investigates the impact of edible coatings on the extended shelf life of pointed gourd and green chillies. A set of 3-point gourds and green chillies were divided into five groups – one was a control group, and the other four combinations of edible coatings were made of chitosan, chitosan with clove essential oil, beeswax, and beeswax with essential oil. Weight loss, visible decay, and visual surface colour change was evaluated. The control groups, to which no coating was applied, showed a loss in weight of 7.5% and visible decay starting from day 6. In contrast, the groups coated with chitosan showed a significantly reduced weight loss of 3.2% and delayed decay appearance until day 15. The most successful coating, however, was a combination of chitosan and clove essential oil. These outperformed the others by not only lowering weight loss to 1.8% but also delaying obvious degradation until day 15 at ambient temperature. The results showed that the coated samples experienced a longer shelf-life and less weight loss than the control sample. Further, the edible coatings with clove essential oil managed to reduce the microbial load of yeast and molds and it also increased antioxidant properties. Among the treated samples, chitosan incorporated with clove essential oil showed superiority in all enlisted parameters.

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Introduction

The process of degradation and spoilage occurs naturally in all fruits and vegetables. It can happen as soon as the nutrients are removed. During ripening and senescence, these vegetables are at risk of developing decay. A significant portion of the vegetables and fruits produced worldwide are lost due to spoilage[1]. Various microbes capable of causing infections and microbiological decay in fruits and vegetables can contaminate the food at any point from farm to table. Microorganisms such as molds, yeasts, and both beneficial and harmful bacteria contribute to the spoilage of fruits and vegetables. While parasites pose a potential threat to food safety, their impact on the sensory qualities of produce is minimal, and they are not commonly associated with the deterioration of whole or freshly cut vegetables[2]. Maintenance of the microbiological integrity of fresh vegetables and fruits during commercial production and distribution processes is challenging, as produce retains metabolic activity while moving from the time of maturity to the period reaching senescence, and total degeneration. When purchasing fresh fruits, consumers typically evaluate their quality based on appearance and freshness[3]. Coating, a technique involving the application of a protective layer on fruits or vegetables, serves to inhibit microbial intrusion and reduce decay. These coatings, applicable through rubbing, spraying, or immersion, employ environmentally friendly ingredients[4]. In the realm of fresh produce, edible coatings have traditionally served to mitigate harm to vegetable cells, achieving prolonged shelf life by diminishing moisture content, solute dispersion, gas exchange, aerobic respiration, oxidative reactions, and visible disorders[5]. This technology applies not only to whole and freshly cut fruits and vegetables but also to nuts, seeds, and cheese. The simplicity of application and the use of eco-friendly components make these coatings a viable solution for enhancing food preservation and safety in the fresh produce sector[6].

Belonging to the Cucurbitaceae family, the pointed gourd (*Trichosanthes dioica* Roxb.), often referred to as the king of gourds, is renowned for its enhanced nutritional and therapeutic properties, particularly in regulating blood sugar and total cholesterol levels. Native to the Indian subcontinent, these gourds are initially classified as non-climacteric but exhibit climacteric behaviour post-harvest, marked by an increased respiration rate. Traditional storage methods prove inefficient as the fruits quickly deteriorate, displaying symptoms such as shrivelling, skin yellowing, hard seed development, and susceptibility to fungal infections[7]. Pointed gourds experience substantial moisture loss (8%–9%) from their initial weight, leading to pronounced surface wrinkling, and they exhibit a very short shelf life of 3–4 d under standard storage conditions. Rapid chlorophyll depletion results in the pulp and skin turning yellow, making such gourds less appealing to consumers. In response, traders and retailers resort to the use of potentially harmful chemicals to enhance the fruits appearance and extend its shelf life. Solutions containing copper sulphate and malachite green are usually applied to mask the undesirable yellow color of the fruit[8].

A vital economic crop and commonly used spice, the chilli plant, scientifically known as *Capsicum annuum* L. and belonging to the Solanaceae family, faces various postharvest challenges. Notably, its short shelf life, high perishability, and susceptibility to fungal diseases result in quality deterioration, chilling damage when stored below 7 °C, and rapid weight loss leading to shrivelling. Despite these challenges, chilli remains a globally significant cash crop, highly valued for its widespread use as a spice[9]. India holds a central position in influencing the global chili market, contributing around 36% of the world's chili production, surpassing 1.4 million tons. Remarkably, India is the foremost chilli exporter globally, claiming a 25% share in international trade and exporting 0.209 million tons, solidifying its dominance in the global chilli landscape[10]. Challenges arise from the innate non-climacteric nature of green chillies. Their vulnerability to microbial infections is exacerbated by the elevated moisture content, ranging from 60% to 85% at harvest. Losses in the chilli supply chain predominantly result from moisture content (15%–25%), field spoilage (1%–10%), transportation from fields to factories (6%–10%), and losses during assembly for distribution (2.5%–5%). Addressing these factors is crucial for mitigating losses and ensuring the efficiency of the chilli supply chain[11].

An edible coating is a type of barrier that helps to maintain the quality and freshness of vegetables and fruits by preventing oxidation, dehydration, and microbial contamination[12,13]. One possible strategy to lessen postharvest deterioration and maintain quality during storage appears to be the application of a coating that is edible. It enhances the physical attributes and flavor of fruits and vegetables by adding essential oils. Due to their antioxidant, antimicrobial, and flavour-enhancing properties, the addition of essential oils in these coatings has gained widespread attention[14]. In addition to being able to enhance the appearance and flavor of fruits and vegetables, essential oils can also help preserve them by providing natural compounds such as eugenol[15]. The essential goal of consumable coating is to restore or strengthen the natural barricade where it has been eliminated by transporting and cleaning. Additionally, it does not give the product any unfavourable qualities and can be taken without any harm to health. Fruit respiration rate is slowed down, water loss is prevented, texture and flavour are preserved, and fragrance compounds, moisture exchange, and partial barriers to CO_2 and O_2 are all partially blocked by edible coatings[16].

By the ingredients utilized during preparation, edible coatings are divided into three categories: (i) lipids like waxes, acylglycerol, and fatty acids; (ii) proteins or polysaccharides, and (iii) composites[17,18]. Lipid coatings have superior water vapour barrier qualities because they are hydrophobic. Lipid materials are often used to improve the appearance of fruits and vegetables even though they are not able to polymerize on their own. Examples consist of waxes and natural resins (gum), essential oils of citrus fruits (camphor), and animal and vegetable oils (coconut, peanut, palm, cacao, butter, fatty acids)[19]. Proteins have more flexible structures than lipids and polysaccharides, which allows them to create bonds in a variety of locations and provide films with better mechanical properties. The dietary quality of the coated foodstuffs is improved by these protein-based films, which also function as efficient coatings. This group includes plant-based proteins like corn, soy, wheat, cottonseed, rice, and peanut as well as proteins like casein, whey protein, gelatine, and egg albumin[20]. Polysaccharide coatings are susceptible to significant moisture absorption due to their hydrophilic properties. They do, however, stick effectively to the cross sections of vegetables and fruits and have minimal permeability to gases[21]. This category includes natural gums (acacia, gum arabic, guar, etc.)[22,23]. Composite-based multicomponent edible coats are also used in this regard. Composite coatings are made up of lipid-based compounds, proteins, and polysaccharides. It can be utilized to decrease the gas permeation and increase the strength and water vapour resistance[24]. Composites can be divided into the following two groups by combined entities and bilayer materials. Double-layer composites are prepared using two layers linked with the same or different coating materials. Examples of these coating materials are protein/protein, polysaccharides + protein, lipid + lipid, lipid + polysaccharides, etc.[25].

Chitin and chitosan are biopolymers that offer a vast array of structural alterations through chemical and mechanical processes, resulting in the creation of unique properties, functions, and applications. The entire family of linear heteropolysaccharides that are soluble in acid is referred to as chitosan The degree of N-deacetylation has not been used to establish a clear nomenclature border between chitin and chitosan[26,27]. Due to its versatile qualities and numerous applications, chitosan is highly desirable in food packaging. Chitosan finds extensive use in both the food industry and agriculture among its many other applications[28]. In most organic solvents, chitin remains insoluble, whereas chitosan can easily be dissolved in acidic solutions that are diluted with a pH of less than 6.0. The amino groups' presence suggests that chitosan's charged state and other characteristics are significantly changed by pH.

The complex substance known as beeswax is secreted in liquid form by unique wax glands in the abdomen of immature worker bees, which are between the ages of 12 and 18 d. The material that makes up a honeycomb's structure is beeswax, which is secreted by the bees to construct the structures that hold honey. Beeswax is found in beauty products due to its rich hydrophobic protective properties. Furthermore, beeswax is utilized in the food sector. Pure beeswax is nearly white when it is secreted by the bee; it only takes on a variable, intense yellowish color upon contact with honey and pollen, and after approximately four years, it turns brown due to the presence of the cocoon[29].

The eugenol present in clove trees and other phenolic compounds extracted from floral buds (*Syzygium aromaticum* L.) demonstrates notable antibacterial and antioxidant properties. This essential oil, known for its efficacy against significant foodborne pathogens[30], possesses anti-free radicals and metal chelating capabilities, functioning effectively as a bactericide. Despite its powerful attributes, the strong and distinct odour of clove oil has restricted its applications in the food industry. To address this limitation, encapsulation has been proposed as a viable strategy for mitigating the potent smell associated with clove oil[31].

Recent studies have shown using Carnauba wax (1.0% and 0.50%), the sensory quality of pointed gourd treated with Carnauba wax was initially good to very good but deteriorated significantly by the 6th day of storage which offered benefits such as delayed ripening and reduced water loss, their efficacy in maintaining sensory quality and extending shelf life appears limited[32]. In another study involving coatings developed with starch, ethylenediaminetetraacetic acid (EDTA), and sodium alginate, the composite coatings were effective in extending the shelf life of green chillies[33]. However, the weight loss in coated samples (5.60%–6.90%) was still relatively high compared to the uncoated samples (12.35%)[34]. Priyadarshi et al.[34]

has studied the effect of chitosan/citric acid-based packaging film pouches on the shelf-life of green chilli. The authors have shown that the shelf life can be slightly improved or affected by the application of an active packaging system. Therefore, a better alternative is proposed, the combination of chitosan with essential oil and beeswax with essential oil could be a better alternative to Carnauba wax and composite coatings developed with starch, EDTA, and sodium alginate or chitosan/citric acid.

This research work presents and discusses the chitosan and beeswax-based functional coating to understand the possible applications of these coatings to evaluate the quality and freshness of pointed gourd and green chilli in real-time. These coatings offer enhanced antimicrobial properties, reduced weight loss, and better preservation of sensory quality, making them more effective in extending the shelf life of green chillies and pointed gourds.

Methodology

Samples

Chitosan (75%–85 % deacetylated) was obtained from Sigma-Aldrich (St. Louis, MO, USA). Glycerol was obtained from Loba Chemie (Mumbai, India). Beeswax and essential oils were purchased from the local market, Phagwara, Punjab, India. Green chillies of equal size, colour, and maturity were purchased from the nearby market, Moga, Punjab, India. Pointed gourds commonly called parwals were also bought from the local market, Phagwara, Punjab, India. The green chillies were chosen based on their uniformity in size, color (green), and maturity (fully ripe), while the pointed gourds were selected for consistency in size, color (green), and maturity (medium stage of ripening). Any other reagents used in this study were of analytical grade and used without any purification.

Method

The experimental requirements consisted of fresh pointed gourd and green chillies, they were carefully selected for their physical condition, devoid of injuries, and exhibiting uniformity in color, size, and maturity. To make sure that optimal hygiene of the experimental fruits was followed and therefore a washing process was initiated utilizing sodium hypochlorite as a chlorine-based cleaner. This process involved immersing the fruits in chlorine-infused water for 10 min. Subsequently, the washed fruits were left to air dry under a fan, ensuring a thorough drying process. The coating application involved immersing the prepared fruits in the respective coating solutions for 5 min. Following each immersion, the fruits were extracted from the solution and allowed to air dry for an additional 10 min post-coating application, both the coated and uncoated samples were systematically arranged on plastic trays and stored at an ambient temperature of 25 ± 2 °C and a relative humidity of 70%–80%.

Preparation of samples

The selection of samples was done with uniform colour, size, and maturity and devoid of any injuries. Then the sample was washed properly for 5−7 min. Washed fruits are then allowed to air dry completely. The selected green chillies and pointed gourd were divided into five groups according to the type of coating (M1 = uncoated fruits, M2 = coated with only chitosan, M3 = coated with chitosan and clove essential oil, M4 = coated with only beeswax, and M5 = coated with beeswax and clove essential oil). Each group contains three green chillies and three pointed gourds. Both chillies and pointed gourd were cleaned with water for 5−7 min and air dried before applying the edible coating. The samples were immersed in the coating solution for 5 min and then were kept for air drying for 10 min. The same procedure was repeated three times for both chillies and the pointed gourd sample.

Preparation for coating

There were five treatments: M1 (control sample), M2 (only chitosan coating 2%), M3 (chitosan 2% + 0.1% (w/w) clove essential oil), M4 (only beeswax coating), and M5 (beeswax + 0.1% (w/w) clove essential oil).

Chitosan coating (M2) - prepared by taking 2 g chitosan and dissolving it in 0.5% acetic acid in distilled water. This was then placed on a magnetic stirrer for 8−10 h. The pH was adjusted to 5.60 by adding 50% citric acid. Then 0.2 mL glycerol was added to act as a plasticizer.

Chitosan incorporated with clove essential oil coating (M3) – chitosan solution - prepared by taking 2 g chitosan and dissolving it in 0.5% acetic acid in distilled water. This was then placed on a magnetic stirrer for 8−10 h. Then the pH was adjusted to 5.60 due to the addition of 50% citric acid. Then 0.2 mL glycerol was added. Essential oil solution - prepared by combining 1 mL of clove essential oil, 0.5 mL of Tween-20, and 8.5 mL distilled water in a test tube. 1 mL of this essential oil solution was then added to the previously prepared chitosan solution and thoroughly mixed for 15−20 min on a magnetic stirrer.

Beeswax coating (M4) – prepared by taking 20 g beeswax, melting it at 55−60 °C and then filtering it. 80 mL of edible oil (rice bran oil) and 0.2 mL glycerol were dissolved in melted beeswax and then thoroughly mixing and used for coating.

Beeswax incorporated with clove essential oil coating (M5) – prepared by taking 20 g beeswax and melting it at 55−60 °C and then filtering it. 80 mL of edible oil (rice bran oil) and 0.2 mL of glycerol were added along with melted beeswax. The solution was then stirred until homogenous. Clove essential oil solution. One mL of this essential oil solution was added to the beeswax solution and mixed thoroughly.

Antioxidant activity test

The evaluation of scavenging activity for the blended sample was carried out using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) method. DPPH solution was prepared by mixing 4 mg of DPPH in 100 mL of methanol. A 50 mg aliquot of the sample solution was blended with a 10 mL DPPH solution, and absorbance values were recorded post 30-min incubation in the dark. The baseline values were established at 517 nm, the specific wavelength for the DPPH assay. Methanol was used as a blank and only the DPPH solution was referred to as control. The quantification of sample scavenging activity was achieved through a designated equation, and the entire experiment was executed in replicates to ensure the accuracy and reliability of the results. This methodology provides insights into the antioxidant potential of the blended sample through DPPH radical scavenging assessment[35].

$$\text{Free radical scavenging activity } (\%) = \frac{A_c - A_s}{A_c} \times 100$$

where, A_C and A_S were the absorbances of DPPH of the control and sample, respectively.

Application of coating

The application of four distinct coatings on green chilli and pointed gourd surfaces was executed utilizing the immersion method to enhance the adhesion and retention of the coatings. Following each dipping of the chilli and pointed gourd, the residual coating material was allowed to drip off, and this process was iterated three times. Subsequently, the coated pointed gourds and chilli were air-dried until complete desiccation. The dried specimens were then stored under ambient conditions with a temperature of 25 ± 2 °C for subsequent physiochemical analysis by established research protocols.

Shelf-life analysis

The soil on the pointed gourd and green chillies was removed by washing with tap water. To assess the efficiency of the coating solution in preservation, samples were immersed in the solution containing the coating material. Uncoated samples were used as a reference for comparison. The samples were kept in different petri plates and were placed under ambient temperature, with continuous monitoring and recording[36]. Over an 8-d and 15-d storage-life test period an ambient temperature of 25 ± 2 °C and a relative humidity of 70%–80%. The changes in skin color, texture, and weight loss were observed for both coated and uncoated pointed gourds as well as for the chillies. The initial weight of the fruits was recorded at the start of the experiment, and subsequent weights were measured.

Sensory assessment

Throughout the research duration, sensory characteristics were meticulously evaluated using a 9-point Hedonic scale. Various aspects, including physical attributes, texture, and overall acceptance, were scrutinized by panellists. For the sensory analysis, a panel of four trained evaluators was assembled, comprising three male teachers and one female teacher. The panellists were selected from the faculty members of the college conducting the research, representing a diverse age range. The ages of the panellists varied between 30 and 50 years. As the sensory analysis was repeated at fixed intervals the faculty members were familiar with the experimental protocol and provided valuable insights into the changes observed in the appearance and colour of the pointed gourds and green chillies. This approach ensured rigorous and reliable sensory evaluations. The scale, ranging from extremely liked (9) to extremely disliked (1), provided a nuanced assessment of the sensory attributes. This comprehensive approach enabled a detailed exploration of the subjective preferences and responses to the sensory qualities of the subject under investigation[37].

Weight loss

The assessment of the storage impact on the 3-pointed gourd and green chillies involved weighing both samples at the commencement and conclusion of each storage interval. The total weight loss during storage was calculated by determining the difference between the initial and final weights of the fruit. To quantify this loss, percentages were computed based on the fresh weight of the fruit. This methodology provides insights into the perishability and stability of three pointed gourd and green chillies over time, aiding in understanding their post-harvest behaviour and potential shelf life[38].

$$\text{Loss in weight (\%)} = \frac{\text{(Initial wt.} - \text{Final wt.)}}{\text{(Initial wt.)}} \times 100\%$$

Results and discussion

The coating formulation was successfully prepared using chitosan and beeswax alone and in combination with clove essential oils. The developed formulation was applied for coating applications. Shelf-life analysis of pointed gourds and green chillies was performed by coating them with an edible coating made from chitosan, beeswax, chitosan with clove essential oil, beeswax with essential oil and one control sample with no coating. The results are displayed in Tables 1–6. Tables 1 & 2 shows the sensory analysis and weight loss for pointed gourd and Tables 3 & 4 show the sensory analysis and weight loss for green chillies, while the effect of coating on pointed gourd and green chillies are presented in Tables 5 & 6 respectively. M1 in the tables represents a sample without any coating to assess the impact of edible coating on raw fruit, M2 represents the coating with chitosan, M3 represents coating with chitosan and clove essential oil, M4 represents coating with beeswax and M5 represents coating with beeswax and clove essential oil. Pointed gourd samples were analyzed for 8 d and the observation was made every 2 d. The samples were analyzed based on sensory analysis and weight loss. The sensory evaluation was based on the changes in the color and the overall appearance of the pointed gourd

Based on the obtained results and per the evaluation it can be concluded that there was a minimum change in the pointed gourd and chillies sample coated with chitosan + clove essential oil which is followed by pointed gourd and chillies coated with beeswax + clove essential oil. The control sample showed the maximum change in the overall appearance in both cases. Physiological losses in weight increase gradually in all the treatments with the advancement of the storage period. The loss in weight in uncoated pointed gourd was observed from 12.71% to 24.72%. The pointed gourd sample coated with chitosan and chitosan + clove essential oil showed an increase in weight loss from 1.7% to 7.60%, and 0.05% to 0.82% respectively. The pointed gourd coated with beeswax and beeswax + clove essential oil showed an increment of weight loss from 2.39% to 11.3%, and from 0.89% to 4.67% respectively. Only limited work has been done on pointed gourd coating and the Carnauba wax (1.0% and 0.50%) coating on the pointed gourd showed

Table 1. Representing sensory evaluation of pointed gourds.

Treatments	Sensory properties (days in storage)			
	2	4	6	8
M1	7.67 ± 0.82	5.67 ± 0.47	3.33 ± 0.47	1.33 ± 0.47
M2	8.33 ± 0.47	7.67 ± 0.47	5.67 ± 0.47	5.33 ± 0.47
M3	8.67 ± 0.47	8.33 ± 0.47	7.63 ± 0.47	7.07 ± 0.47
M4	7.67 ± 0.47	7.33 ± 0.47	6.3 ± 0.47	4.67 ± 0.47
M5	8.33 ± 0.47	7.67 ± 0.47	7.21 ± 0.47	6.84 ± 0.82

Table 2. Representing weight loss of pointed gourds during storage.

Treatments	Physiological loss in weight (%) (days in starage)			
	2	4	6	8
M1	12.71 ± 2.91	18.57 ± 2.68	22.11 ± 1.18	24.72 ± 0.21
M2	1.70 ± 0.16	3.40 ± 0.32	5.91 ± 0.45	7.60 ± 0.26
M3	0.05 ± 0.01	0.25 ± 0.11	0.59 ± 0.20	0.82 ± 0.33
M4	2.39 ± 0.21	5.46 ± 0.48	9.97 ± 1.10	11.3 ± 0.78
M5	0.89 ± 0.30	1.76 ± 0.52	3.82 ± 0.41	4.67 ± 0.31

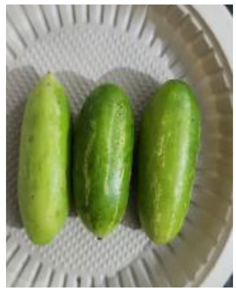
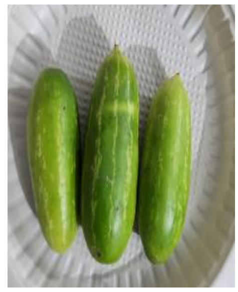
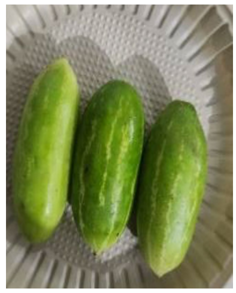
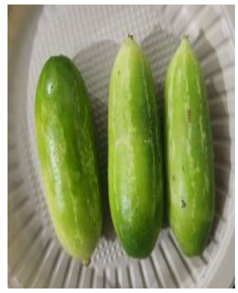
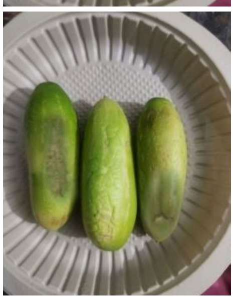
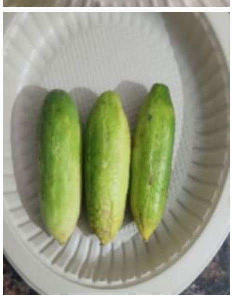
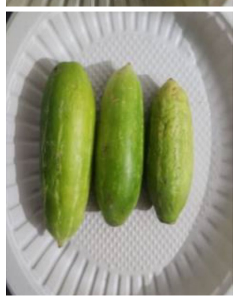
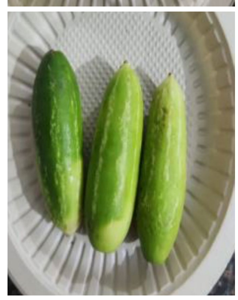
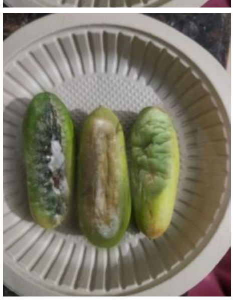
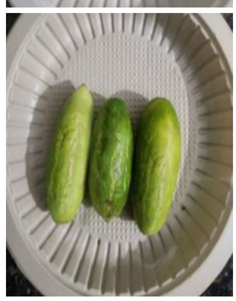
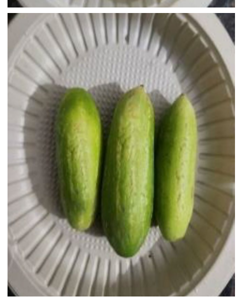
Table 3. Representing sensory evaluation of green chillies.

Treatments	Sensory properties (days in storage)				
	3	6	9	12	15
M1	7.67 ± 0.47	6.3 ± 0.47	4.67 ± 0.47	2.67 ± 0.94	1.67 ± 0.47
M2	8.33 ± 0.47	7.67 ± 0.47	6.33 ± 0.94	6.00 ± 1.41	5.00 ± 0.82
M3	8.67 ± 0.47	8.33 ± 0.47	8.00 ± 0.82	7.67 ± 0.47	7.33 ± 0.47
M4	7.67 ± 0.47	6.84 ± 0.47	5.33 ± 0.47	5.00 ± 0.81	4.66 ± 0.47
M5	8.67 ± 0.47	8.33 ± 0.47	7.67 ± 0.47	7.33 ± 0.47	6.67 ± 0.47

Table 4. Representing weight loss of green chillies during storage.

Treatments	Physiological loss in weight (%) (days in storage)				
	3	6	9	12	15
M1	3.26 ± 0.73	4.37 ± 1.2	6.36 ± 0.92	11.67 ± 1.3	15.34 ± 1.10
M2	0.92 ± 0.31	1.23 ± 0.35	3.86 ± 0.75	5.45 ± 0.23	8.45 ± 1.20
M3	0.40 ± 0.21	0.96 ± 0.23	1.40 ± 0.46	1.95 ± 0.74	2.30 ± 0.36
M4	1.81 ± 0.73	2.62 ± 0.47	4.77 ± 0.18	5.11 ± 0.54	6.21 ± 0.27
M5	0.69 ± 0.19	0.98 ± 0.23	3.21 ± 0.46	3.40 ± 0.36	4.47 ± 0.63

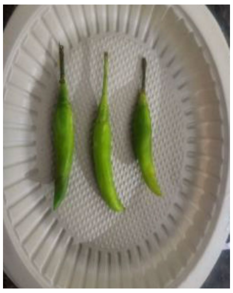
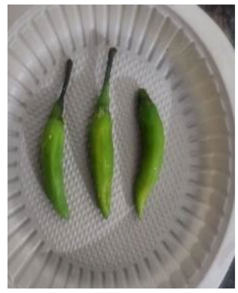
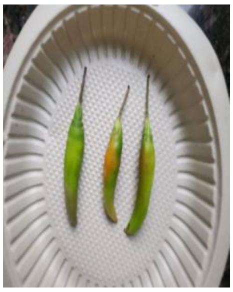
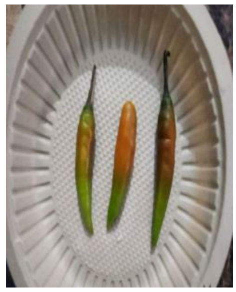
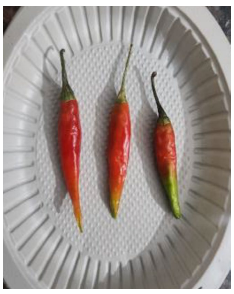
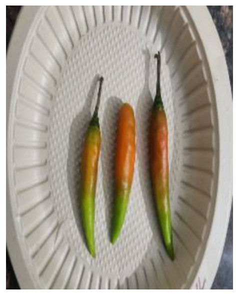
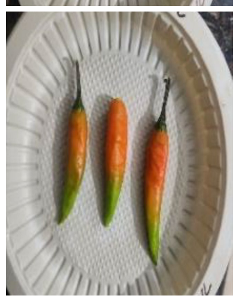
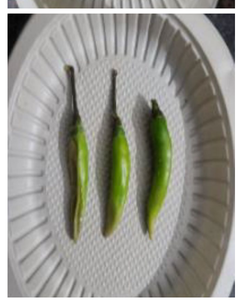
Table 5. Visual records of pointed gourd coated and uncoated for 8 d.

Days	M1	M2	M3	M4	M5
2					
4					
6					
8					

earlier some promising results[32]. The sensory quality of pointed gourd treated with Carnauba wax was found to be primarily appealing, but the shelf life declined meaningfully after storage for 6 d which indicates although the coating is beneficial for delaying ripening and reducing water loss, its usefulness in preserving sensory quality and extending shelf life still appears restricted.

The sample of fresh green chillies was analyzed for 15 d and the observation was made every 3 d and analysis was done based on sensory analysis and weight loss. The sensory evaluation focused on color and overall appearance changes in the chillies. The findings suggest minimal alterations in the chilli sample coated with chitosan + clove essential oil, followed closely by chillies coated with beeswax + clove essential oil. In

Table 6. Visual records of green chillies coated and uncoated for 15 d.

Days	M1	M2	M3	M4	M5
3					
6					
9					
12					
15					

contrast, the control sample exhibited the most significant changes in overall appearance. Notably, the chitosan-only coating displayed better color retention compared to the sole beeswax coating. These results underscore the effectiveness of combined coatings, particularly with chitosan and clove essential oil, in preserving the visual attributes of chillies, highlighting their potential for enhancing the shelf life and consumer appeal of the produce.

During storage at room temperature, changes in weight loss were observed in both the control and coated green chillies samples. Uncoated green chillies experienced a notable increase in weight loss, escalating from 3.26% to 15.34%. In contrast, chillies coated with chitosan and chitosan + clove essential oil showed a rise from 0.92% to 8.45%, and 0.40% to 2.30%, respectively. Additionally, chillies coated with beeswax and beeswax + clove essential oil demonstrated an increase in weight loss from 1.81% to 6.21% and from 0.69% to 4.47%. These findings indicate the potential of coatings, particularly chitosan and beeswax, in mitigating weight loss during storage, contributing to the preservation of green chillies. A similar result was reported in the case of alginate/carboxymethyl cellulose/starch-based coating for green chilli preservation[39]. The application of an edible coating of green chilli significantly enhanced the shelf life by reducing moisture loss. The color and texture of the coated chilli were superior compared to the uncoated counterpart. Similarly, coatings were developed using starch, EDTA, and sodium alginate, and used in maintaining the shelf life of green chillies[33]. The authors showed that the weight loss in coated chillies samples (5.60%–6.90%) was still relatively high compared to the uncoated samples (12.35%). The same authors also studied the shellac-based surface coating on green chillies in combination with modified atmosphere packaging (MAP)[40]. The coated chillies exhibited longer shelf life compared to the uncoated counterpart and the use of MAP in combination with coating further extended the shelf life of chilli. Thus, the combined treatment could be very effective in preserving the shelf life of chilli. The effect of edible gum arabic and chitosan-based coating on green chillies has also been recently studied[41]. The obtained results showed that the application of the edible coating on chilli significantly improved the shelf life by maintaining the respiration rate and vitamin C content. In another work, chitosan/citric acid film was used to make pouches for green chilli packaging[34]. The biopolymer-made pouches used for green chilli packaging showed some effect on the color and shelf life of chilli due to the presence of citric acid but the effect was not pronounced due to the lack of presence of a strong functional ingredient in the packaging system. The presence of essential oil in the current packaging system and direct coating application showed an overall better effect in improving the shelf-life of chilli.

Antioxidant activity

DPPH analysis was carried out for the control sample, chitosan-coated sample, chitosan with clove essential oil-coated sample, and clove essential oil sample. No antioxidant activity was observed in the control, whereas in the chitosan-coated sample, it was found to be 17.3% ± 0.1%, in the case of the chitosan with clove essential oil-coated sample it was found to be 31.4% ± 1.0%, while in the case of clove essential oil 67.1% ± 1.5%. Therefore, it can be concluded that the control sample shows no radical scavenging activity since it has no added antioxidant coating. The chitosan-coated sample exhibits moderate antioxidant activity compared to the control as chitosan is known for its antioxidant action owing to the presence of function hydroxyl and amine group at carbon number six and two respectively[42]. The chitosan with clove essential oil-coated sample shows a much higher antioxidant activity compared to the control and chitosan-coated samples but less than only clove essential oil. The clove essential oil-coated sample shows the highest antioxidant activity among all three tested samples which is presumably due to the presence of strong antioxidant compounds such as eugenol, monoterpenes, propanoids, caryophyllene, etc.[43,44].

Conclusions

Coating is an effective method for the improvement of the shelf life of fruits and vegetables. Chitosan, known for its biodegradability and environmental friendliness, boasts potent antimicrobial properties that make it a superior choice for various applications including food packaging. Beeswax, a natural and renewable resource offers remarkable water-repellent qualities, providing surfaces with robust protection against moisture and physical damage. Combining chitosan with clove essential oil results in a coating with heightened antimicrobial activity, offering broader protection against diverse microorganisms while enhancing the flavour and aroma of coated products. Similarly, blending beeswax with clove essential oil yields a coating with enhanced antimicrobial efficacy that may improve adhesion, and a delightful sensory experience, making it an excellent choice for preserving the freshness and quality of various products.

The edible coating can be used in the shelf-life extension of pointed guard and green chillies. Weight loss, visible decay, and visual surface color change of the tested food were evaluated for 15 d. The results showed that the coated samples experienced more self-life and less weight loss than the control sample. The samples coated with chitosan + clove essential oil showed minimum changes in the appearance making it a suitable combination for shelf-life extension. After chitosan + clove essential oil, the samples coated with beeswax + clove essential oil showed minimum changes in the samples. Pointed gourd and green chilli samples coated with chitosan and beeswax displayed little variation in the physical appearance and made them fall behind the samples coated with beeswax + clove essential oil respectively. Hence inference can be drawn that chitosan with clove essential oil and beeswax with clove essential oil are the most potent methods for shelf-life extension in the case of pointed gourd and green chillies. Still, there is scope as well as the need for further improvement in edible functional coating. The work presented here is a preliminary study and thus needs further research for the practical implementation of this work for active food packaging purposes.

Author contributions

The authors confirm contribution to the paper as follows: conceptualization, validation: Vidyarthi EV, Khela RK, Thakur M, Roy S; methodology: Vidyarthi E, Khela RK, Thakur M; writing—original draft preparation: Vidyarthi EV, Khela RK, Thakur M; writing—review and editing, visualization, supervision: Roy S. All authors have read and agreed to the published version of the manuscript.

Data availability

All data generated or analyzed during this study are included in this published article.

Conflict of interest

The authors declare that they have no conflict of interest.

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