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Application of Chitosan Edible Coating Using Dip and Spray Method on Postharvest Quality of Cavendish Banana

Aplikasi Edible Coating Kitosan Menggunakan Metode Celup dan Semprot terhadap Mutu Pascapanen Pisang Cavendish

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ABSTRACT

Applying postharvest technologies such as edible coatings is one of effective method to extend the shelf life of bananas. Chitosan, an edible biopolymer, has excellent film-forming properties that allow it to coat fruit surfaces and prolong freshness. The coating method plays a crucial role in the effectiveness of edible coatings. This study aimed to evaluate the effect of coating method on the postharvest quality of Cavendish bananas through statistical analysis. In this research, 1.25% chitosan solution was applied using two methods: dipping and spraying, with uncoated bananas serving as the control. A knapsack power sprayer was used to apply the coating solution in the spray treatment. Bananas were stored at room temperature (26 ± 2°C) and 80 ± 5% relative humidity for 11 days. Results showed that spray-coated bananas experienced the lowest weight loss (14.51%) and disease severity score (3.33), highest value in L* (53,88), b* (30,97), pH (5,82) and pulp-to-peel ratio (2,57), firmest texture (28,06 mm/150g/5sec) along with slowest starch conversion (45%) by day-5. In comparison, dip-coated bananas lost 15.32% weight, highest TSS value (15,87), 65% degraded starch by day-5, lowest a* value (-0,44), and higher disease severity of 4.17. Uncoated bananas showed 15.25% weight loss, completely degraded starch by day five, and the highest disease severity (5.00). These findings indicate that the spray application of chitosan is more effective than dipping in maintaining banana quality during storage and supports its practical application in commercial postharvest handling.

Keywords: cavendish banana; chitosan; dip-method; edible coating; spray-method

ABSTRAK

Penerapan teknologi pascapanen seperti pelapis edible *merupakan salah satu metode yang efektif dalam memperpanjang umur simpan pisang. Kitosan merupakan bahan pelapis* edible *yang dapat melapisi permukaan kulit buah dengan baik sehingga menghambat respirasi dan memperpanjang umur simpannya. Jenis metode pelapisan menjadi faktor yang penting dalam aplikasi pelapis* edible*. Penelitian ini bertujuan mengevaluasi pengaruh metode pelapis pada mutu pasca panen pisang cavendish melalui analisis statistik. Pada penelitian ini, larutan kitosan (1,25%) diaplikasikan menggunakan metode celup dan semprot, dengan pisang tanpa pelapis sebagai pembanding.* Sprayer *gendong bermotor digunakan untuk menyemprotkan larutan pelapis. Penyimpanan pisang dilakukan pada suhu ruang (26 ± 2ºC) dengan RH 80 ± 5% selama 11 hari. Hasil penelitian menunjukkan bahwa pisang yang dilapisi kitosan dengan metode semprot mengalami penyusutan bobot (14,51%) dan nilai keparahan penyakit terendah (3.33), nilai tertinggi L** (53,88), *b** (30,97), *pH* (*5,82) dan rasio bobot daging terhadap kulit (2,57*)*, tekstur paling keras* (28,06 mm/150g/5sec) *dan laju konversi pati yang paling lambat (45%) pada hari ke-5 penyimpanan. Sebaliknya, pisang dengan pelapisan celup menunjukkan penyusutan bobot sebesar 15,32%, nilai total padatan terlarut tertinggi (15,87), degradasi pati 65% pada hari ke-5, nilai a* terendah (-0,44), dan tingkat keparahan penyakit 4,17. Pisang tanpa pelapis mengalami penyusutan 15,25%, degradasi pati total pada hari ke-5, dan tingkat keparahan penyakit tertinggi (5,00). Hasil ini menunjukkan bahwa aplikasi kitosan dengan metode semprot lebih efektif dibandingkan metode celup dalam mempertahankan kualitas pascapanen pisang selama penyimpanan, serta mendukung penerapan penanganan pascapanen di tingkat komersial.*

Kata kunci: *kitosan; metode celup; metode semprot; pelapis* edible*; pisang Cavendish*

INTRODUCTION

Banana (Musa spp.), particularly the Cavendish cultivar, is one of the most commercially important tropical fruits worldwide. The Cavendish variety alone contributes to nearly half of global banana production, with an estimated annual output of approximately 50 million tons (Food and Agriculture Organization, 2025; Varma et al. 2025). Its widespread popularity is attributed not only to its appealing sensory attributes, but also to its nutritional value and ease of consumption, making it a convenient fruit for global consumers. Despite its economic significance, banana's rapid postharvest ripening presents a major challenge in maintaining fruit quality during storage and distribution. As a climacteric fruit, banana exhibits a distinctive ethylene biosynthesis pattern characterized by a sharp surge followed by a rapid decline in ethylene production during the early climacteric phase (Yamamoto et al., 2018). This physiological trait accelerates ripening, leading to a shortened shelf life and increased postharvest losses. To address this issue, the development and application of effective postharvest technologies are crucial to delay ripening, extend shelf life, and improve marketability.

One of the postharvest technologies that can be applied is edible coating, a thin layer made from edible material that covers the surface of perishable foods such as vegetables and fruits. Edible coatings act as a semi-permeable barrieriff to gases (O_2 and CO_2), moisture, and ethylene, which helps reduce respiration rate, water loss, and oxidative reactions—three key factors that accelerate ripening and spoilage. This technology offers several advantages: it is simple to apply, cost-effective, environmentally friendly, delays the ripening process, enhances appearance, and helps inhibit microbial growth (Owusu-Akyaw and Oduro, 2021; Raghav et al., 2016). Edible coating materials are generally categorized into three main groups: hydrocolloids (proteins and polysaccharides), lipids, and composites (Sharma et al., 2018).

Chitosan is one of the most widely studied edible coating materials due to its excellent film-forming ability, mechanical strength, and functional bioactivity (Raghav et al., 2016). Chitosan is a polysaccharide produced by the deacetylation process of chitin, which can be obtained from the exoskeleton of crustaceans, such as shrimp and crabs, insects, mollusks, and cell walls of fungi (Jianglian and Shaoying 2013; Harkin et al. 2019). Chitosan is favored over other coating materials such as alginate or starch-based polymers because of its unique antimicrobial properties, in addition to being biocompatible, biodegradable, and non-toxic (Luo & Wang, 2013). As an edible coating, chitosan functions not only as a semi-permeable barrier to gases and moisture but also provides antimicrobial protection through a biochemical mechanism. Its positively charged amino groups interact with negatively charged microbial cell membranes, disrupting their integrity, and inhibiting microbial growth, which in turn helps delay disease development during storage (Jianglian & Shaoying, 2013). Several studies have shown that a decent concentration of chitosan solution can effectively inhibit the change of weight loss, color, firmness, total titratable acid, and total soluble solids of bananas during postharvest storage (Malmiri et al. 2011; Suseno et al. 2014; Hossain and Iqbal 2016).

Edible coatings can be applied using various methods, including dipping, spraying, and brushing. Most studies on chitosan-based edible coatings in bananas have primarily employed the dip method. Dipping is the oldest and most widely used commercial technique; however, it is less economical, as it requires a large volume of coating solution that is reused across multiple applications, which also increase the risk of cross-contamination from previously dipped products (Garnida, 2020; Owusu-Akyaw and Oduro, 2021). Additionally, the uncontrolled accumulation of solute concentration in the solution over time may alter the coating properties.

In contrast, the spray-coating method is considered more efficient and hygienic, particularly for industrial-scale applications. It is more cost-effective, as it requires a smaller volume of coating solution, reduces material waste, and enables better control over layer thickness and distribution. This results in more uniform surface coverage, making it more favorable for large-scale use (Garnida, 2020). Nevertheless, to the best of our knowledge, studies investigating the application of chitosan edible coatings using the spray method on fruits remain limited. Therefore, this study aimed to evaluate the effectiveness of a 1.25% (w/v) chitosan solution applied via dip and spray methods in maintaining the postharvest quality of Cavendish bananas during storage.

METHODOLOGY

Equipment and Material

The equipment used in this study included homogenizer (Armfield FT40, UK), refractometer (ATAGO N-1E, Japan), a penetrometer (PRECISION Scientific, USA), pH meter (Horiba Laqua pH1100 S, Japan), chromameter (Konica Minolta CR-400, USA), centrifuge (Eppendorf Centrifuge 5810 R, Germany), motorized knapsack sprayer (SWAN PS-20, Indonesia), patternator, digital balance, hand mixer, glassware, room thermometer, smartphone camera (OPPO Reno 5), mini photo studio (31.5 cm × 31.5 cm × 29.5 cm) with 5500K LED lighting, and a set of computers.

The material used included Cavendish bananas with maturity stage 2 and finger cut, purchased from a banana produsent in Tangerang, Indonesia. The banana was visually selected for uniformity in weight (100–150 g), green peel color, and the absence of physical damage and fungal infections. Chitosan flakes (food grade, medium molecular weight, and 89% deacetylated) were obtained from CV. Bio Chitosan Indonesia. Glycerol was used as a plasticizer and Tween 80 as a surfactant, both purchased from Merck (Merck KGaA, Germany).

Experimental Design

The research was conducted at the Department of Food Science and Technology and the Department of Mechanical and Biosystems Engineering, Faculty of Agricultural Technology, IPB University. The single-factor experiments were laid out in a completely randomized design (CRD), consisting of three treatment groups: dip-coated bananas, spray-coated bananas, and uncoated bananas (control).

Two biological replications were carried out at different postharvest times. In each replication, eight quality parameters were observed. Destructive parameters included pulp-to-peel ratio, firmness, total soluble solids, starch-to-sugar conversion, and pH. Non-destructive parameters included weight loss, color, and disease severity. Destructive parameters required different bananas for each time point, while non-destructive parameters were measured repeatedly on the same fruits. Observations were conducted on days 0, 1, 3, 5, 7, 9, and 11 of storage, with day 0 referring to the day treatments were applied before storage. Visual changes in banana appearance were also documented daily.

For each parameter, measurements were taken in triplicate using three different bananas per treatment per observation day. With three treatments, seven observation days, a group of destructive parameters, a group of non-destructive parameters, triplicate measurement, and two replications from different post-harvest time, a total of 156 bananas were required for the entire experiment. Data obtained were analyzed using ANOVA test ($P<0.05$) and followed by the Duncan Multiple Range Test (DMRT) using SPSS 27 software.

Table 1. Disease severity scale

Fruit surface rotten (%)	Score
0	1
1-25	2
26-30	3
51-75	4
76-100	5

Chitosan Coating Preparation

The Chitosan solution (1.25% w/v) was prepared based on the method by Park et al. (2004), with modifications to the ingredient concentrations and mixing conditions. The corresponding amount of chitosan flakes was gradually added to 0.6% acetic acid solution, followed by manual stirring. Chitosan concentration in this study was referred from the previous study done by Lustriane et al. (2018). After complete addition, the mixture was homogenized at 18,000 rpm for 7 minutes at room temperature (26 ± 2°C, RH 80 ± 5%). By using a homogenizer, chitosan could be perfectly dissolved in a relatively short time. Glycerol (25% w/w chitosan) and Tween 80 (0.1% w/v) were added during the mixing. The pH of the chitosan solution was adjusted to 5.6 by gradually adding 1 M NaOH, as this pH provides optimal biological activity and solubility of chitosan (Stossel et al., 1984; Toskas et al., 2013). The prepared chitosan solution was used in fresh condition to preserve its functional properties (No et al., 2006).

The Application of Chitosan Edible Coating

The application of chitosan edible coating to banana was carried out using the dip and spray methods. In the dip method, bananas were immersed in the coating solution for two minutes (Lustriane et al. 2018). For the spray method, bananas were placed with a 6 cm spacing on a 1.5 m² grid mat. A knapsack power sprayer filled with the chitosan coating solution was used, with the spraying pressure set to 4 kg/cm². The nozzle was positioned at a fixed height of 58 cm, and each banana was sprayed for 5 seconds to ensure uniform coverage. These sprayer settings were determined through preliminary trials. After the bananas were sprayed on one side, it was air-dried at room temperature for one hour (26 ± 2°C, RH 80 ± 5%), then the opposite side was treated similarly. No coating was applied to the uncoated group (control). All bananas were placed in fruit baskets and stored at room temperature (26 ± 2°C, RH 80 ± 5%) for 11 days.

Weight Loss

Weight loss (%) was measured using a digital scale. The value was presented in percent (%) and calculated using the following formula:

$$Weight\ loss\ (\%) = \frac{IW\ day\ 0 - FW\ of\ day\ i}{IW\ (day\ 0)} x\ 100\% \qquad (1)$$

IW : initial weight (day 0)
FW : final weight of day-i (0, 1, 3, 5, 7, 9, 1

Pulp-to-Peel Ratio

The pulp-to-peel ratio of the banana was calculated by separately weighing the pulp and peel using a digital scale. The ratio value was obtained by dividing the pulp weight to the peel weight (Tourky et al., 2014).

Fruit Firmness

Fruit firmness was measured using a penetrometer. The fruit firmness value was determined by the depth of the probe penetrating the unpeeled banana. Probe was penetrated through stalk, middle, and tip with a 150 g load for five seconds. The obtained data were presented as a mean in mm/150 g/5 seconds.

Total Soluble Solid

The total soluble solid content was determined using a refractometer, following the method described by Lustriane et al. (2018). The fruit pulp was destructed into puree, then centrifuged at 4000 rpm for 5 minutes. The filtrate was dropped into the refractometer prism. The total soluble solid value was presented in ºBrix, which indicates the ratio between the speed of light in a vacuum and its speed through the sample. A higher total soluble solids content causes light to travel more slowly through the sample, resulting in a higher °Brix reading (Kusumiyati et al. 2020).

Starch-to-Sugar Conversion

The starch-to-sugar conversion was measured using the iodine test (Lustriane et al., 2018). The starch-iodine color solution was prepared by dissolving 1% potassium iodide and 0.25% iodine in distilled water. A 2–3 cm thick transverse slice from the middle section of the banana was dipped into the starch-iodine solution for five seconds. For quantitative analysis, the resulting starch staining pattern on the surface of the banana slice was compared to the banana starch-iodine staining chart developed by Blankenship et al. (1993).

Fruit pH

pH of the fruit was measured using a pH meter at a room temperature (25 ± 1ºC). The pH meter was initially calibrated using buffer solutions with pH 4.0 and pH 7.0. The electrode was immersed in a banana pulp until a stable pH value was obtained.

Fruit Color

The banana peel color was measured using chromameter which calibrated using a standard white plate. The position selected for color measurement was the stalk, middle, and the tip of the banana. The color was described in CIELab scale coordinate (CIE, 1978), including light (L; 0-100), greenness (-a) or redness (+a), and blueness (-b) or yellowness (+b) (Juncai et al., 2015). In addition to the single-color coordinate, the total color change (ΔE*) was also measured using the following formula:

$$\begin{aligned} \Delta L* &= L*0 - L*f \\ \Delta b* &= b*0 - L*f \\ \Delta a* &= a*0 - a*f \\ \Delta E^* &= \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2} \end{aligned} \qquad (2)$$

0 = Value at day-0
F = Value at day-1, -3, -5, -7, -9, -11

Disease Severity

Disease severity represents the intensity of quality deterioration observed on the fruit peel, such as browning, brown spot, damage, and mold. The measurement was done by visual observation and scored using the scale developed by Sivakumar et al. (2008) as follows Table 1.

RESULTS AND DISCUSSION

Weight Loss

As a climacteric fruit, a banana ripens through respiration, transpiration, and ethylene gas, causing physical changes and affecting its shelf life. Respiration refers to the formation of energy that allows metabolic activity in the fruit to continue. Respiration requires O_2 and generates CO_2, H_2O, and heat. Meanwhile, transpiration is a process of humidity loss triggered by difference in water vapor pressure between the product surface and the environment (Becker and Fricke 2002). The respiration and transpiration processes are responsible for the fruit weight loss and affect the fruit texture and taste, thus decreasing the fruit quality.

The chitosan edible coating application to banana forms a thin physical layer that covers the stomata, thereby limiting gas exchange. This barrier delays the respiration and transpiration processes, inhibits water loss, and helps maintain the fruit's weight during storage (Suseno et al. 2014). Figure 1 displays the effect of chitosan coating with dipping and spraying methods on the banana weight loss during the storage. Weight loss increased progressively for all treatments throughout the storage period, which is commonly associated with moisture evaporation through transpiration and respiration. However, the spray-coated bananas consistently exhibited the lowest weight loss, followed by dip-coated and uncoated samples, especially after day 5.

Although statistical analysis indicated no significant differences (p ≤ 0.5) between treatments at all time points, the observed trend suggests that the spray method may provide a better moisture barrier. The superior performance of the spray coating could be attributed to its more uniform and thinner layer, which improves adherence and coverage while avoiding the pooling or uneven film thickness often observed in the dip method (Garnida, 2020). A study by Lustriane et al. (2018) reported that 1.25% chitosan coatings significantly delayed weight loss in Cavendish bananas when applied via dipping. Our results indicate that while dipping is effective, the spray method may optimize the protective effect, potentially enhancing postharvest handling strategies for commercial applications.

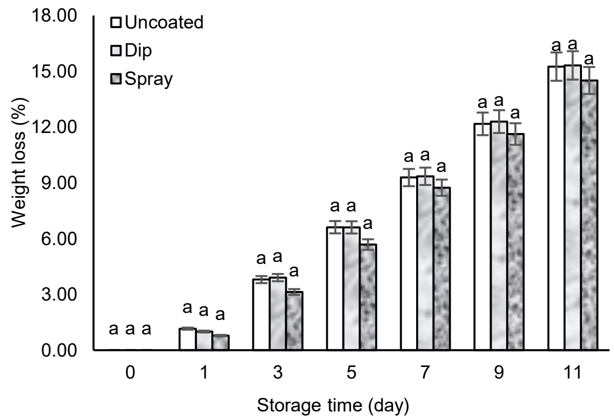

Figure 1. Weight loss of banana fruits during storage at 26±2 °c in different time. Whiskers indicate standard deviation. The values marked with the same letter do not differ significantly according to Duncan's multiple range tests (P < 0.05).

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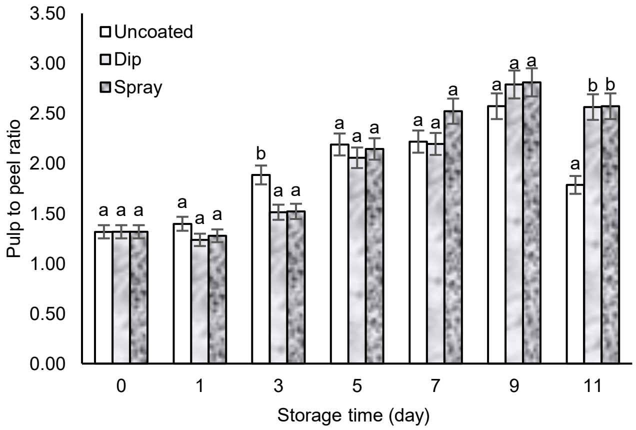

Figure 2. Pulp-to-peel ratio of banana fruits during storage at 26±2 °C in different time. Whiskers indicate standard deviation. The values marked with the same letter do not differ significantly according to Duncan's multiple range tests (P < 0.05).

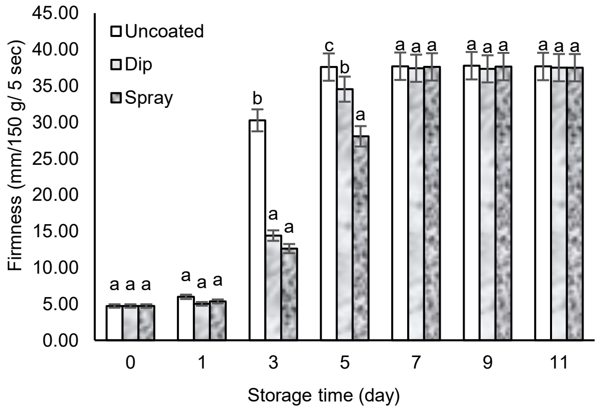

Figure 3. Firmness of banana fruits during storage at 26±2 °C in different time. Whiskers indicate standard deviation. The values marked with the same letter do not differ significantly according to Duncan's multiple range tests (P < 0.05).

The primary cause of fruit weight loss is water loss during the respiration process (Eshghi et al., 2014). Respiration is also influenced by the relative humidity of the environment. As humidity decreases, the rate of water loss increases, which accelerates the ripening process (Duan et al., 2007). In this study, bananas were stored at a relative humidity of 80 ± 5%, while the optimal relative humidity for banana ripening is 95-100%, and for storage, it is 90-95% (Duan et al., 2007). This environmental condition may affect the effectiveness of the chitosan coating in reducing weight loss, leading to no significant differences (P ≤ 0.05) in weight loss between coated and uncoated bananas during storage.

Pulp to Peel Ratio

The energy generated during the respiration process is used to convert starch into sugar. This starch-to-sugar conversion occurs rapidly, leading to changes in osmotic pressure and the transfer of water from the peel into the pulp. Additionally, water in the peel evaporates due to the transpiration process. As a result, mature bananas tend to have lighter, thinner skins, making them easier to peel, while the pulp becomes heavier. This shift contributes to an increased pulp-to-peel ratio during the ripening period (Adi et al., 2019).

Figure 2 shows the effect of chitosan coating with dip and spray methods on the banana's pulp-to-peel ratio during the storage period. On the day-3 and -11, both spray and dip methods of chitosan application showed a statistically significant effect (p ≤ 0,5) compared to uncoated banana, suggesting that chitosan coating helps delay the ripening process as also reported by Lustriane et al. (2018). In contrast, Yamamoto et al. (2018) found that such treatments did not significantly retard changes in this ratio. On day 1, spray-coated bananas had a slightly lower ratio, possibly due to initial moisture retention in the peel, resulting from the film's gas barrier effect

From day 5 to 9, all treatments showed a gradual increase in pulp-to-peel ratio, reflecting typical ripening behavior as water migrates from peel to pulp, increasing turgidity and pulp volume. However, by day 11, the ratio declined slightly for all treatments, with the sharpest decline in uncoated bananas. This suggests entry into the senescence phase, where metabolic processes deteriorate, possibly causing the peel to reabsorb water from the pulp or leading to tissue collapse and moisture redistribution.

Interestingly, while earlier studies (Lustriane et al., 2018; Yamamoto et al., 2018) reported a continued increase in the pulp-to-peel ratio beyond day 11, our findings suggest

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accelerated senescence in uncoated samples, and a moderated transition in coated bananas. This supports the hypothesis that chitosan coating not only delays ripening but also prolongs fruit firmness and structural integrity during later stages of storage.

Fruit Firmness

Starch degradation that occurs in banana pulp causes the texture to become softer during the ripening period (Eshghi et al. 2014). Furthermore, the banana peel also undergoes polysaccharide degradation that forms cell walls such as pectin, hemicellulose, and cellulose, which are responsible for the air space formation in middle lamella and softening the fruit peel texture (Wang et al. 2013; Adi et al. 2019). The application of a chitosan-based edible coating can help maintain banana firmness by forming a semi-permeable film on the fruit surface that reduces gas exchange and delays the respiration rate. This coating also inhibits ethylene action and slows down enzymatic activity related to cell wall degradation, such as polygalacturonase and cellulase, thereby delaying softening. Additionally, by minimizing water loss and preserving cell turgor, chitosan contributes to better texture retention throughout storage (Ali et al. 2011).

Figure 3 shows the effect of chitosan coating with dip and spray methods on the banana firmness during storage. Firmness was measured based on the depth of a probe (mm) penetrating the fruit over 5 seconds under a 150 g load. A higher penetration value indicates lower fruit firmness.

Throughout the storage period, uncoated bananas exhibited a rapid decline in firmness, with a significant softening already evident by day 3. In contrast, both spray-coated and dip-coated banana showed significantly ($P \leq 0.5$) higher firmness retention compared to uncoated bananas, indicating that chitosan coating effectively slowed down fruit softening. The previous study conducted by Aziz et al. (2021) and Shinga et al. (2025) reported a similar result, showing that chitosan coating on bananas exhibit greater firmness retention during storage compared to controls.

By day 5 of storage, a significant difference ($p \leq 0.5$) was observed among all three treatments. Spray-coated bananas exhibited least reduction in firmness, outperforming both dip-coated and uncoated fruits. This suggests that the spray method forms a more uniform and breathable coating layer, enhancing gas exchange control while avoiding the drawbacks of excessive coating thickness often associated with dip methods.

Total Soluble Solid

The fruit's hardness decrease is also followed by an increase in total soluble solid (TSS). The total soluble solid in banana is typically dominated by sugar (glucose, fructose, sucrose), a small number of proteins, amino acids, and organic materials. Before ripening, bananas exhibit relatively low sugar content (~1–2%) and TSS values around 5–8 °Brix. During ripening, enzymatic starch hydrolysis dramatically increases sugar concentration to approximately 15–20 °Brix, with total sugar content reaching 15–20% of fruit weight (Maduwanthi & Marapana, 2017). Sucrose is the dominant sugar in the early ripening stages, while glucose and fructose levels increase significantly in later stages (Huang et al., 2024). This parameter is positively associated with sugar content in the fruit sample. By forming a semi-permeable barrier, chitosan coating can slow down respiration and delay starch hydrolysis, which in turn may moderate the increase in TSS during storage.

Figure 4 shows the effect of chitosan coating with dip and spray methods on the banana's TSS during the storage period. At day 0, all samples had comparable TSS values (~7 °Brix), consistent with unripe bananas that are still starch-rich. As ripening progressed, TSS increased markedly, especially in the uncoated samples, reaching a peak around day 5. This trend reflects the conversion of starch into soluble sugars during ripening, aligning with compositional changes observed by (Emaga et al., 2008).

Coated bananas—especially those treated via the dip method—exhibited slower increases in TSS, indicating a delay in starch breakdown and sugar accumulation. On day-11, all treatments show a slight reduction in TSS value. Similar to the trend observed in the pulp-to-peel ratio, this may indicate the onset of the senescence phase. The decline was first noticeable in uncoated bananas on day-9, while dip-coated bananas showed the least reduction.

Similar studies by Wang et al. (2013); Kusumiyati et al. (2020); Aziz et al. (2021) reported that 1.25% of chitosan solution using dip method could inhibit the total soluble solid changes better than uncoated banana. Chitosan's gas barrier properties reduce O_2 availability, which in turn limits ethylene biosynthesis and respiration rate, thereby slowing the activity of starch-degrading enzymes (Wang et al., 2013; Aziz et al., 2021). This effect could be more pronounced in dip-coated bananas due to the formation of a thicker and more consistent coating, potentially restricting gas exchange and slowing ripening kinetics (Kusumiyati et al., 2020).

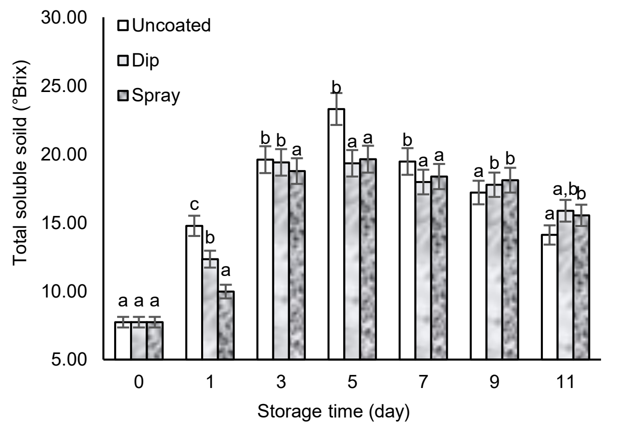

Figure 4. Total soluble solid of banana fruits during storage at 26±2 °C in different time. Whiskers indicate standard deviation. The values marked with the same letter do not differ significantly according to Duncan's multiple range tests ($P < 0.05$).

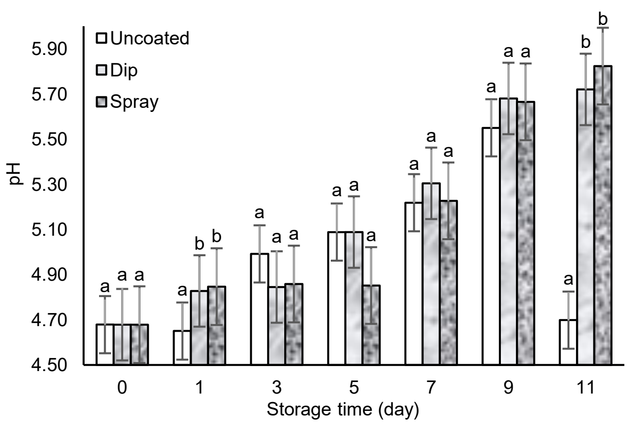

Figure 5. pH of banana fruits during storage at 26±2 °C in different time. Whiskers indicate standard deviation. The values marked with the same letter do not differ significantly according to the Duncan's multiple range tests ($P < 0.05$).

Table 2. The changes of starch pattern of banana pulp during storage at 26±2°C

Coating Method	Storage time (day)						
	0	1	3	5	7	9	11
Uncoated	 15%	 5%	 65%	 *	 *	 *	 *
Dip method	 15%	 15%	 55%	 >65%	 *	 *	 *
Spray Method	 10%	 15%	 25%	 45%	 >65%	 *	 *

*rippen banana

Starch-to-Sugar Conversion

As previously mentioned, energy obtained from respiration is used for degrading starch into sugar. Table 2 shows the effect of the chitosan dip and spray method on banana's starch content during the storage. Quantitative measurements were done by comparing the observation result to the iodine color scale of banana designed by Blankenship et al. (1993). Starch degradation is a key biochemical process during banana ripening, primarily driven by the activity of amylase enzymes, which convert starch reserves into soluble sugars—mainly sucrose, glucose, and fructose (Emaga et al., 2008).

On the third day of storage, uncoated banana exhibited the most significant starch degradation (65%), this indicates the onset of the climacteric phase, during which ethylene production and respiration rates peak, stimulating rapid activation of α- and β-amylases that hydrolyze starch granules (Dadzie & Orchard, 1997). At the fifth day, the starch-iodine pattern was no longer observed in uncoated banana, indicating near-complete conversion.

In contrast, both coated treatments retarded starch degradation, with spray-coated bananas showing only 25% starch loss on day 3, compared to 55% in dip-coated ones. Even on day 5, the spray-coated fruits still retained a visible starch pattern (~45%), while dip-coated bananas retained only a faint pattern (>65% degraded).

Interestingly, despite the slower starch breakdown observed in spray-coated bananas, they showed a greater increase in total soluble solids (TSS) compared to the dip-coated ones. This suggests that the spray method formed a more breathable, uniform barrier, allowing moderate gas exchange that supports enzymatic activity. Consequently, the spray coating achieved a better balance between delaying starch degradation and promoting sugar accumulation, which contributes positively to postharvest quality.

These findings are consistent with previous studies by Wang et al. (2013); Kusumiyati et al. (2020); and Aziz et al. (2021), which demonstrated that a 1.25% chitosan coating applied via dipping could retard starch-to-sugar conversion compared to uncoated bananas. Chitosan's effectiveness lies in its semi-permeable nature, which limits gas exchange, reduces ethylene perception, and thereby delays the activation of genes involved in starch hydrolysis. This mechanism is further supported by the TSS data (Figure 4), where slower starch degradation correlates with a delayed increase in sugar content, confirming that chitosan coatings modulate the starch-to-sugar transition and delay ripening.

Fruit pH

During the ripening process, a banana undergoes a change in organic acid content that affect the pH value. The organic acids found in a banana include malic, citric, oxalic, and tartaric acids. The first two are responsible for bitter tastes of the unripe banana, while oxalic acid contributes to the banana's astringency sensation (Maduwanthi and Marapana 2017).

The initial pH of all samples was similar (~4.6–4.7), but by day 1, coated bananas—particularly those with the dip method—already showed significantly higher pH than uncoated samples ($p \leq 0.5$), indicating early onset of organic acid buffering. However, from day 3 to day 9, all treatments showed a comparable trend in pH increase, reaching approximately 5.6–5.8, with no significant differences between groups.

By day 11, uncoated bananas experienced a drastic drop in pH, while coated samples—especially spray-coated—maintained higher values. This pH drop likely results from tissue senescence and microbial decay, which produce acidic metabolites such as acetic, lactic, and butyric acids as by-products of microbial fermentation (Gol & Ramana Rao, 2011; Vargas et al., 2006). The chitosan coating, known for its antimicrobial properties, may have delayed microbial proliferation, thus suppressed the acidification process, and stabilized the pH in coated fruits (Elsabee & Abdou, 2013). The highest pH values observed in spray-coated bananas further support the notion that the spray method offering better microbial control and enhanced preservation of fruit quality at the late stage of storage.

Interestingly, while prior studies have reported a slightly lower pH in coated bananas due to restricted gas exchange and slower respiration (Gol & Ramana Rao, 2011; Belal et

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al., 2019), our results show higher pH in coated fruits at key time points. This discrepancy might be due to differences in chitosan concentration, coating uniformity, or fruit maturity stage, which can influence acid metabolism rates.

Color

Peel color serves as the major characteristic that consumers observe in order to determine the ripeness level and quality of a banana (Parijadi et al. 2022). Chlorophyll degradation by chlorophyllase causes the banana to undergo color changes during the ripening process. This degradation is also followed by carotenoid formation, such as lutein, α-carotene, and β-carotene, which contribute to the banana's yellow color. After passing the ripening process, the banana undergoes senescence and browning reaction by polyphenol oxidase, resulting in brown spots on the fruit's peel (Adi et al. 2019). Chitosan slows pigment degradation by modulating the internal atmosphere and suppressing ethylene-induced carotenoid synthesis, thereby retarding over-ripening (Hossain & Iqbal, 2016)

Figures 6-9 exhibited the effect of dip and spray coating on the banana's peel color in terms of L* (lightness), a* (green–red), b* (blue–yellow), and ΔE* (total color difference) values over an 11-day storage period. The increased L* and b* values of the banana peel indicated color changes to yellow and the ripening process, while the decreased L* and b* values indicate brown spots on the banana surface and senescence. On the other hand, the increase in a* value indicates reduced green color and the ripening process (Adi et al. 2019).

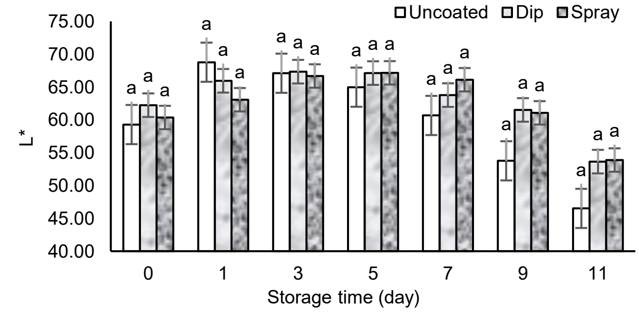

Figure 6. L* value of banana fruits during storage at 26±2 °C in different time. Whiskers indicate standard deviation. The values marked with the same letter do not differ significantly according to Duncan's multiple range tests (P < 0.05).

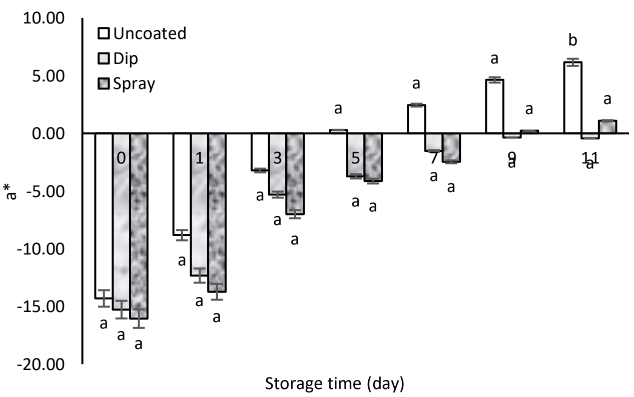

Figure 7. a* value of banana fruits during storage at 26±2 °C in different time. Whiskers indicate standard deviation The values marked with the same letter do not differ significantly according to Duncan's multiple range tests (P < 0.05).

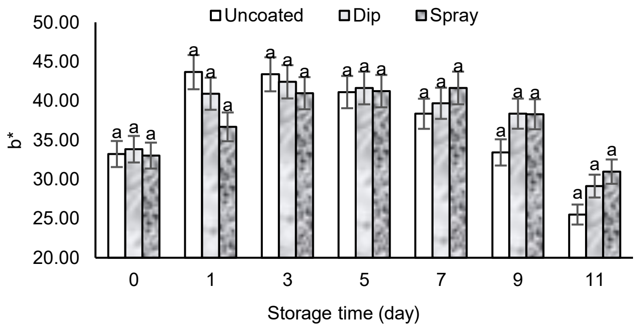

Figure 8. b* value of banana fruits during storage at 26±2 °C in different time. Whiskers indicate standard deviation. The values marked with the same letter do not differ significantly according to Duncan's multiple range tests (P < 0.05).

As seen in Figure 6, the L* values of all treatments increased during the early days of storage, peaking on day 5, then declined afterward. This trend corresponds with peel yellowing followed by browning due to senescence. No significant differences (p > 0.05) were observed among treatments, though spray-coated samples consistently maintained slightly higher L* values. This may be attributed to the chitosan film's semi-permeable nature, which restricts oxygen diffusion and delays oxidative browning reactions (Lustriane et al., 2018). The maintained L* values reflect the inhibition of enzymatic browning, particularly by suppressing polyphenol oxidase (PPO) activity.

In Figure 7, the a* values steadily increased from negative (green) toward zero or slightly positive values (red) throughout the storage period, reflecting the gradual loss of chlorophyll and progression of ripening. A statistically significant difference (p < 0.05) was observed on day 11, where dip-coated bananas exhibited the lowest a value*, indicating a superior ability to preserve green pigmentation compared to both spray-coated and uncoated samples. This suggests that the dip method formed a thicker or more uniform chitosan layer, effectively limiting oxygen permeability and slowing ethylene-induced chlorophyll degradation. While both coating methods delayed ripening, dip-coating demonstrated greater efficacy in maintaining the fruit's green hue. This observation aligns with known mechanisms of chlorophyll degradation during ripening, as described by Dadzie and Orchard (1997) and Emaga et al. (2008), though specific effects of coating methods were not evaluated in those studies.

Although quantitative analyses indicate that the dip-coating method more effectively delayed color change during ripening, qualitative observation in Table 3 reveals that spray-coated bananas retained a slight green hue even up to day 11. This residual greenness, while potentially reflecting prolonged chlorophyll retention, may negatively influence consumer perception, as Cavendish bananas are typically preferred when fully yellow. Therefore, while spray-coating shows promise in extending shelf life, its impact on visual appeal presents a potential limitation that warrants further optimization.

Figure 8 shows that b* values increased steadily until day 7 before declining, indicating initial color development (yellowing) followed by browning. The b* values were not significantly different among treatments (p > 0.05), though coated bananas had marginally lower b* values during the late storage period. This suggests that chitosan slows pigment degradation by modulating the internal atmosphere and suppressing ethylene-induced carotenoid synthesis, thereby retarding over-ripening (Hossain & Iqbal, 2016).

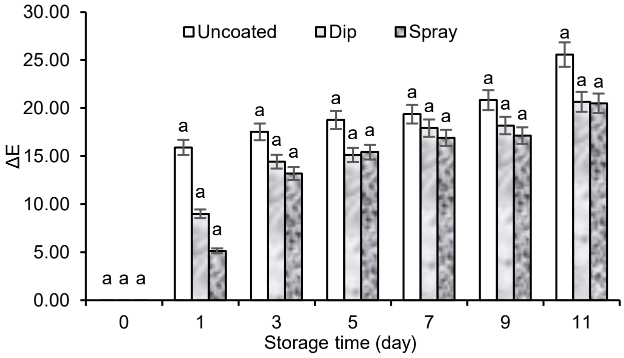

Figure 9. ΔE* value of banana fruits during storage at 26±2 °C in different time. Whiskers indicate standard deviation. The values marked with the same letter do not differ significantly according to the Duncan's multiple range tests (P < 0.05).

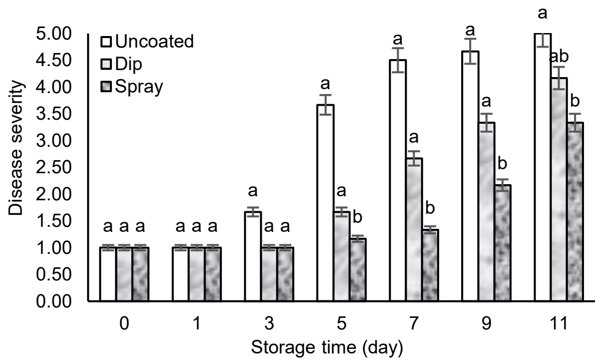

Figure 10. Disease severity of banana fruits during storage at 26±2 °C in different time. Whiskers indicate standard deviation. The values marked with the same letter do not differ significantly according to the Duncan's multiple range tests (P < 0.05)

Table 3. The change of banana appearance during storage at 26±2°C

Coating Method	Storage time (day) 0–11
	0 1 2 3 4 5 6 7 8 9 10 11
Uncoated	
Dip method	
Spray method	

Figure 9 presents the ΔE* values, showing cumulative color change from day 0. The uncoated bananas experienced the greatest increase in ΔE*, especially after day 5, with a final value exceeding 25. Although not statistically significant ($p > 0.05$), coated bananas—especially spray-treated ones—exhibited slower color shifts, indicating better color retention. The ΔE* progression reflects both ripening and senescence processes, and the data imply that chitosan coating mitigates rapid peel color degradation.

Previous studies by Hossain and Iqbal (2016) and Aziz et al. (2021) reported the effect of chitosan-based edible coating on banana color during storage by measuring the color change on a numeric scale. The study by Aziz et al. (2021) reported that 0.5% and 2% chitosan-based coating could retard the color changes of the banana. A study by Hossain and Iqbal (2016) with 1% chitosan concentration also reported similar findings. According to Lustriane et al. (2018), chitosan-based coating may serve as a surface barrier that decreases the O_2 and CO_2 exchange, thus inhibiting ethylene gas production and chlorophyll degradation on the banana peel. In addition, chitosan-based coating can result in the peel's glossy appearance, thus improving the consumers' acceptance of the product (Elsabee and Abdou 2013).

Disease Severity

Figure 10 displays the effect of dip and spray methods on bananas' disease severity during storage, while Table 3 shows the effect of dip- and spray coating on appearance. No browning was noticed at day-0 (the treatment day before storage) and day-1 in all three different treatments of banana. From day 2 until day 11, the uncoated banana exhibited the highest disease severity score. On the day-4 of storage, brown spots were noticed only on the uncoated bananas, which progressed to rotting by day 8 and mold development on the fingertip by day 11 (Table 3). In contrast, the coated bananas did not exhibit mold growth, likely due to the antimicrobial properties of chitosan (Ibañez-Peinado et al., 2020). Chitosan coating may also inhibit interactions between enzymes and oxygen, thereby preventing the emergence of brown spots (Pierre, 2016).

Both dip- and spray-coated bananas effectively prevented browning and damage to the banana peel, reducing disease severity. The spray-coated bananas exhibited a lower severity score than the dip-coated

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bananas, indicating that the spray method more effectively mitigates disease severity than the dip method. Studies on chitosan-based coatings for bananas, including those by Aziz et al. (2021) with 0.75% and 2% concentrations, Belal et al. (2019), and Hossain and Iqbal (2016) with 1% concentration, further support that such coatings can reduce disease severity in bananas.

CONCLUSION

This study demonstrated that the application of chitosan-based edible coatings using both dip and spray methods has significantly influenced the postharvest quality of Cavendish bananas. The two-application delayed ripening indicators compared to uncoated controls, yet they exhibited different mechanisms and degrees of effectiveness.

Spray-coated bananas maintained higher firmness, slower visual starch degradation, while also increased TSS, indicating an efficient starch-to-sugar conversion. This combination supports improved palatability and desirable texture during storage. These effects are likely due to its thinner and more uniform film that provided a more balanced gas exchange and moisture. Additionally, spray method also superior in reducing weight loss, lowering disease severity, and better maintenance of pulp-to-peel ratio throughout the storage period. The antimicrobial property of chitosan, particularly in the spray-coated samples, also contributed to higher pH values at the end of storage, implying delayed microbial activity and senescence. Conversely, the dip-coating method demonstrated superior performance in slowing TSS accumulation and delaying peel color changes, possibly due to its thicker film and enhanced gas barrier characteristics.

These findings underscore the potential of chitosan coatings, especially spray applications, as low-cost, biodegradable solutions to reduce postharvest losses in banana supply chains. From an applicative perspective, the spray method offers a practical advantage for scalable commercial implementation, providing better coating uniformity and less material waste. However, the visual retention of green color in spray-coated bananas at later stages may reduce consumer acceptance, suggesting the need for further optimization of coating composition or thickness. Future research should explore the effect of chitosan coatings under real supply chain environments, assess consumer perception of coated bananas, and examine the cost-effectiveness and environmental impact of scaling the spray method for commercial applications.

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