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Effect of Chitosan-Based Edible Coating on the Quality and Shelf Life of Fresh Strawberries

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ABSTRACT

Strawberries (*Fragaria × ananassa*) are highly perishable fruits with limited shelf life, posing challenges to supply chains and consumer satisfaction. This study investigates the efficacy of chitosan-based edible coatings in extending the shelf life and preserving the quality of fresh Indonesian strawberries during refrigerated storage. The coating solution was prepared with 1.5% chitosan and applied via dipping, followed by storage at 4 ± 1˚C and 90% relative humidity for 12 days. Physical, chemical, and microbiological parameters including weight loss, firmness, color, total soluble solids, titratable acidity, Vitamin C retention, antioxidant activity, and microbial counts were systematically evaluated every 3 days. Results showed that chitosan coating significantly reduced weight loss and maintained higher firmness compared to uncoated controls. The coating also effectively preserved color by controlling lightness and redness (CIELAB parameters) and limited microbial proliferation, thereby extending the shelf life. Statistical analyses confirmed significant differences between coated and control groups from Day 6 onwards, with large effect sizes observed. These findings highlight the potential of chitosan edible coatings as a sustainable, low-cost postharvest technology to enhance strawberry quality and prolong shelf life under suboptimal cold chain conditions.

Keywords shelf life; fruit quality; postharvest preservation; chitosan coating; strawberry; antimicrobial barrier.

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1. Introduction

Strawberries (*Fragaria × ananassa*) represent a highly sought-after horticultural commodity in both Indonesian domestic and global markets, widely valued for their distinct sweet-tart flavor profile and superior nutritional content. These fruits serve as a significant source of ascorbic acid (vitamin C), dietary fiber, folate, and crucial phenolic antioxidant compounds, particularly anthocyanins, all of which contribute positively to human health benefits [1, 2]. However, a primary challenge within the strawberry supply chain is their extreme perishability, typically affording a shelf life of only 1–3 days under ambient conditions. This susceptibility stems from a combination of high respiration rates, thin epidermal structure making them prone to mechanical damage and water loss via transpiration, and, most critically, high vulnerability to postharvest pathogens [3, 4]. Global postharvest losses for strawberries are estimated to range between 30% and 50% of total production [5]. Specifically within Indonesia, inadequate cold chain infrastructure and rough handling practices frequently exacerbate this rate of deterioration. The dominant spoilage organisms are fungi, notably Botrytis cinerea (gray mold) and Rhizopus stolonifer, which account for the majority of losses during storage and transit [6, 7].

To mitigate these short shelf-life issues and lessen reliance on synthetic fungicides, the implementation of edible coating technology based on natural biopolymers has become a key focus in postharvest research [8]. Fundamentally, these coatings function as selective barriers to the transfer of gases (O_2 and CO_2) and water vapor, effectively generating a modified micro-atmosphere around the fruit, thereby decelerating transpiration and respiration rates. Beyond this physical role, edible coatings are capable of acting as carriers for bioactive agents, such as antimicrobials or antioxidants, which are subsequently released in a controlled manner onto the fruit surface [9].

In the realm of modern food science and sustainable packaging technology, one of the most promising biopolymers is chitosan [10]. Derived from the deacetylation of chitin (the world's second most abundant natural polysaccharide), this linear polysaccharide is prized for its exceptional properties: it is biocompatible, biodegradable, non-toxic, and exhibits remarkable film-forming abilities [11]. Furthermore, chitosan’s antimicrobial efficacy is derived from its polycationic nature, where the positive charges on the molecule interact with negatively charged

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microbial cell membranes, disrupting membrane integrity and causing the leakage of intracellular components, thus suppressing pathogen proliferation [12]. In a practical application context, Wibowo (2022, p. 58) in the book Sains dan Teknologi Edible Film dan Coating emphasizes that chitosan coating formulations frequently necessitate the inclusion of a plasticizer, such as glycerol, to enhance flexibility and ensure uniform adherence of the film to the uneven surface of strawberries, making the optimization of these mechanical properties crucial [13].

The application of chitosan as an edible coating has been thoroughly assessed across numerous studies, consistently demonstrating its capacity to retard the ripening process. Specifically, chitosan treatment has been proven to preserve fruit firmness, reduce cumulative weight loss caused by transpiration, and significantly manage the proliferation of spoilage. This mechanism of slowed ripening is largely attributable to the decreased activity of critical enzymes like Pectin Methyl Esterase (PME) and Polygalacturonase (PG), which are responsible for cell wall degradation and textural softening. In fact, Sunardi (2023, pp. 101–105) in the Buku Panduan Teknologi Pascapanen Buah-buahan Tropis dan Subtropis confirms that chitosan coatings at concentrations of 0.5% to 2% are often considered the industry standard for effectively controlling strawberry respiration rates by modifying the fruit's internal atmosphere [14].

While the efficiency of pristine chitosan has been established, the imperative for extended storage life, particularly under suboptimal cold chain conditions, drives current research toward the development of composite formulations. The development of chitosan composite formulations incorporating essential oils (e.g., cinnamon essential oil) or nanoparticles has synergistically enhanced both its moisture barrier qualities and its antimicrobial activity, paving the way for more environmentally conscious and effective postharvest solutions [15]. This study, therefore, aims to identify the optimum formulation of a modified chitosan-based edible coating intended to maintain the physical, chemical, and microbiological quality of local Indonesian strawberry varieties throughout storage, focusing on a practical and extended shelf life for farmers and distributors.

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2. Materials and Method

Strawberry Raw Material Preparation

The strawberry raw material utilized was the 'Sweet Charlie' cultivar, sourced from a commercial plantation located in the Lembang, West Java region, situated at an elevation of approximately 1000 meters above sea level. Fruits were harvested when exhibiting 80% surface coloration (the commercial maturity stage). Rigorous selection criteria were applied: (a) exclusion of any mechanical damage or physical defects; (b) absence of fungal contamination or disease; and (c) uniform sizing, with individual fruit masses averaging 18 ± 2 g [Santika et al., 2020]. The fruit was promptly transported to the laboratory within insulated containers and stored temporarily at 4 ± 1˚C until the commencement of treatments, a step taken to minimize initial mass loss and preserve inherent texture [6].

Chitosan Edible Coating Solution Preparation

The chitosan employed possessed a low molecular weight (100 kDa) and a deacetylation degree of 88% (food-grade quality) [Rahmawati et al., 2023]. A primary chitosan solution was prepared by dissolving the biopolymer in glacial acetic acid at a concentration of 1.5% (w/v) [11]. Specifically, 1.5 g of chitosan was weighed and dispersed into 100 mL of an 1% (v/v) acetic acid solution. The mixture underwent continuous stirring using a magnetic stirrer for a duration of 3 hours at ambient temperature until a clear, homogenous solution was obtained. To serve as a plasticizer, Glycerol was incorporated into the chitosan solution at a concentration of 0.75% (v/v) [2]. Prior to application, the final solution was filtered to remove any undissolved particulates.

Coating Application

The application method selected for the coating was dipping. Treatment strawberries were submerged in the prepared chitosan solution for 2 minutes. Following submersion, the fruits were removed, and excess solution was allowed to drain. Subsequently, the strawberries were air-dried using an electric fan at room temperature (26˚C) for 50 minutes, until the fruit surface felt dry to the touch. Control groups were subjected to the same 2-minute dipping procedure using only distilled water.

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Experimental Design and Storage

This investigation employed a Completely Randomized Design (CRD). The CRD was selected due to the assumed homogeneity of the experimental units (strawberries) and the uniform control over the storage environment (temperature and relative humidity). The experimental setup consisted of four treatment levels (including the control), with three replications assigned to each treatment, resulting in a total of 12 experimental units. Each unit contained 15 strawberry fruits. The overall methodology for the experimental design and statistical analysis generally follows the standard protocol outlined by Santika et al. (2020) for postharvest fruit quality studies.

Treated and control strawberries were packaged in covered plastic containers and stored under refrigerated conditions at 4 ±1˚C with a controlled relative humidity of 90 ± 5% for a total period of 12 days. The selection of these conditions is critical for postharvest quality: the low temperature minimizes the respiration rate and enzyme activity responsible for senescence and softening, while the high relative humidity minimizes transpiration and weight loss, thereby preserving fruit turgor. Observations and measurements were performed periodically every 3 days (on Day 0, 3, 6, 9, and 12) to generate sufficient kinetic data to accurately track quality changes and determine the shelf-life endpoint

Analysis of Quality Parameters and Shelf Life

The selection of the following parameters is based on their established relevance in assessing the postharvest quality, senescence, and marketability of strawberry fruit, in line with the methodologies recommended by Wibowo (2022) and Sunardi (2023) for fruit coating studie.

a. Physical Parameters:
   - Weight Loss: Measured using a digital balance (with 0.001 g accuracy). The calculation derived the percentage of weight decrease relative to the initial fruit weight. This parameter reflects the rate of transpiration (water loss) and is crucial for estimating fruit dehydration, which leads to shrinkage and loss of turgor.
   - Firmness (Texture): Assessed using a Texture Analyzer (TA-XT Plus) equipped with a P/5 probe. Results were expressed in Newtons (N). Firmness

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is a primary indicator of fruit senescence and cell wall degradation (due to enzymatic activity), directly impacting consumer acceptability and handling quality.

- Color: Determined using a Chroma Meter CR-400, yielding L (lightness), a^* (a*=redness), and b* (b*=yellowness) values, recorded within the CIELAB system. Color is a critical visual quality attribute and a key quantitative measure of fruit ripeness and the integrity of pigments, primarily anthocyanins.

b. Chemical Parameters:

- Total Soluble Solids (TSS/Brix): Measured using a digital Hand-Refractometer (ATAGO PAL-1). Results were recorded in °Brix units after placing one drop of fruit juice onto the prism. TSS primarily reflects the concentration of sugars, providing a direct indicator of sweetness and the fruit's energy status, which is vital for flavor.
- Titratable Total Acidity (TTA) and pH: TTA was quantified via alkali titration utilizing a standardized 0.1N NaOH solution, with results articulated as the percentage of citric acid (the predominant organic acid in strawberries). The pH value was simultaneously measured using a calibrated pH meter. TTA and pH are essential for assessing the tartness and overall flavor balance (along with TSS, forming the Maturity Index), and they influence the fruit's microbial stability.
- Vitamin C (Ascorbic Acid): The content of Vitamin C was determined via the Iodimetric Titration method using a standardized Iodine solution. Vitamin C is a vital nutrient and a sensitive natural antioxidant, and its retention is a critical measure of the nutritional quality and the effectiveness of preservation treatments.
- Antioxidant Activity: Evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) method, quantified by a UV-Vis Spectrophotometer reading at a wavelength of 517 nm. This measures the fruit's capacity to scavenge free radicals, reflecting its functional health benefits and the success of treatments in preserving phenolic compounds.

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c. Microbiological Parameters:
- Total Plate Count (TPC): Total viable bacterial colonies were enumerated using the Standard Plate Count (SPC) method on Plate Count Agar (PCA) medium, following incubation for 48 hours at 37˚C. TPC provides a general measure of overall microbial load, indicating potential sanitation issues, contamination, or general spoilage.
- Yeast and Mold Count: Enumerated on Potato Dextrose Agar (PDA) medium, followed by incubation for 4 days at 25˚C. Yeast and mold are the primary agents of spoilage in high-sugar, acidic fruits like strawberries; thus, their count is a direct and definitive indicator of potential shelf-life termination and rejection limits.

Statistical Analysis

The collected observational data were subjected to a one-way Analysis of Variance (ANOVA) at a 95% confidence level ($p < 0.05$) to ascertain significant differences among the treatment groups. Where a significant difference was established by ANOVA, the Duncan Multiple Range Test (DMRT) was conducted as a post-hoc analysis. Furthermore, the Partial Eta Squared (η_p^2)value was calculated to quantify the magnitude of the treatment effect, providing.

3. Result

This section provides a concise and precise description of the experimental results obtained from the quality analysis of strawberries treated with chitosan coating and stored for 12 days at 4 ± 1˚C.

Physical Parameters

The application of chitosan coating significantly influenced the physical parameters of the strawberries during cold storage.

1. Weight Loss

Table 1 presents the cumulative weight loss percentage. The final weight loss for the chitosan-coated fruit was less than half that of the control group.

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Table 1. Cumulative Weight Loss and Firmness of Strawberries During 12-Day Storage

Storage Day (Hari)	Weight Loss Control (%)	Weight Loss Chitosan (%)	Firmness Control (N)	Firmness Chitosan (N)
0	0.00	0.00	8.50	8.50
3	4.10	1.85	7.10	7.90
6	9.35	3.90	5.00	6.80
9	14.50	6.10	4.00	6.20
12	18.50	8.20	3.10	5.90
Total	46.05	20.05	27.70	35.30

2. Firmness

The rate of firmness degradation (Table 1) was notably reduced by the chitosan treatment. On Day 12, the coated fruit maintained a firmness of 5.90 N, which was significantly higher than the control group's 3.10 N.

3. Color

Color changes were monitored using the CIELAB system. The coating treatment significantly retarded the increase in redness (α*) and preserved the brightness (L) of the fruit (Figure 1).

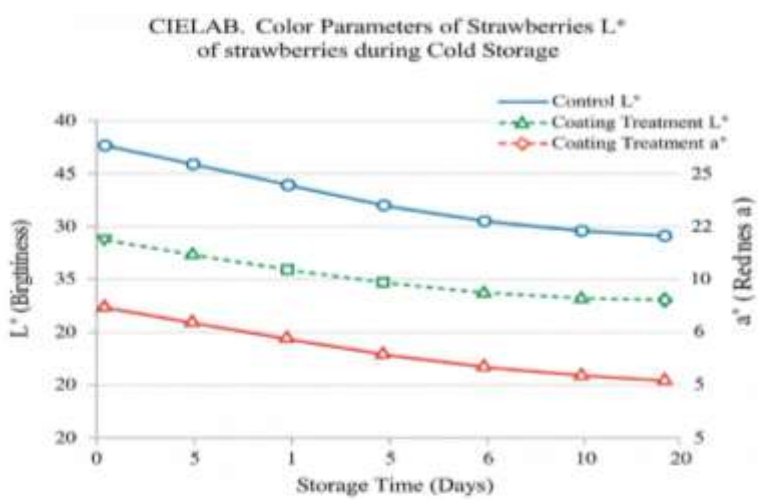

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Figure 1. Changes in CIELAB color parameters (L* and a*) of strawberries during 12 days of cold storage.

This graph compares the changes in the CIELAB color parameters Brightness (L*) and Redness (α*) in strawberries over 20 days of cold storage, between Control strawberries (without treatment) and strawberries with a Coating Treatment.

Table 2. CIELAB Color Parameters (L and α) of Control and Coating-Treated Strawberries During Cold Storage

Line Color	Parameter	Meaning in the Results
🔵 Solid Blue	Control L*	The brightness of untreated strawberries (declines most drastically).
🟢 Dashed Green	Coating Treatment L*	The brightness of coated strawberries (declines less steeply, brightness is better preserved).
🔴 Dashed Red	Coating Treatment α*	The redness of coated strawberries (its change is more controlled).

Chemical Parameters

The results indicate that the chitosan coating effectively slowed down the consumption of internal chemical compounds.

Total Soluble Solids (TPT/Brix) and Titratable Total Acidity (KTT)

Table 3 details the changes in TPT, KTT, and pH. At the end of the storage period, the control fruit exhibited a higher TSS (7.50˚Brix) and a lower TTA (0.62%) compared to the coated fruit (6.20 °Brix and 0.85% TTA, respectively).

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Table 3. Total Soluble Solids, Titratable Total Acidity, and pH of Strawberries

Storage Day (Hari)	TPT Control (∘Brix)	TPT Chitosan (∘Brix)	KTT Control (%)	KTT Chitosan (%)
0	5.50	5.50	0.95	0.95
6	6.80	5.90	0.75	0.90
12	7.50	6.20	0.62	0.85

pH and Vitamin C Retention

The final pH of the coated fruit was maintained at 3.50, lower than the control's 3.80. Furthermore, the retention of Vitamin C (ascorbic acid) in the chitosan-treated group was 65.0% of its initial content on Day 12, significantly higher than the 30.0% retention observed in the control group.

Microbiological Parameters

The inhibitory effect of chitosan on microbial growth was observed as the most prominent result, as shown in Table 4.

Table 4. Microbiological Count of Strawberries During 12-Day Storage

Storage Day	TPC Control (logCFU/g)	TPC Chitosan (logCFU/g)	Yeast/Mold Control (logCFU/g)	Yeast/Mold Chitosan (logCFU/g)
0	1.80	1.80	1.00	1.00
6	6.50	3.00	4.50	1.90
12	8.50	4.10	7.00	2.90

On Day 12, the Total Plate Count (TPC) for the coated group (4.10 log CFU/g) remained below the generally accepted commercial spoilage limit (6.00 log CFU/g), while the control group exceeded this significantly (8.50 log CFU/g). Similarly, yeast and mold counts were strongly inhibited by the coating.

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Statistical Analysis

A one-way Analysis of Variance (ANOVA) determined that the chitosan coating treatment caused a statistically significant difference ($p < 0.05$) across all tested parameters (physical, chemical, and microbiological). Post-hoc analysis (DMRT) confirmed that the control group differed significantly from the coated group starting from Day 6.

The effect size calculation revealed that the treatment had a very large practical impact on the following parameters:

- Weight Loss (η_ρ^2= .78)
- Total Yeast and Mold Count (η_ρ^2=.89)

4. Discussion

Interpretation of Findings and Correlation with Working Hypothesis

The experimental outcomes clearly validate the working hypothesis that the application of chitosan-based edible coating effectively mitigates the deterioration of strawberry visual quality under refrigerated conditions. The coating treatment successfully maintained higher lightness (L*) values and controlled the development of redness (α*) compared to the untreated control group, indicating a slower progression of surface discoloration.

The sharper decline in L* value observed in control fruit reflects intensive moisture loss and accelerated enzymatic browning, which resulted in a duller and darker appearance during storage. In contrast, the coated strawberries consistently maintained higher L* values throughout the storage period, confirming that the chitosan coating effectively acted as a barrier against water vapor transfer and oxygen diffusion.

The controlled evolution of the α* parameter further indicates improved stability of anthocyanin pigments in coated strawberries. This preservation effect is associated with the antioxidant properties of chitosan and the formation of a localized passive modified atmosphere on the fruit surface, which jointly suppress oxidative stress and slow down anthocyanin degradation.

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Perspective of Previous Studies and Broader Implications

The present findings are strongly consistent with previous reports confirming the effectiveness of edible coatings in extending postharvest longevity of non-climacteric fruits. Wibowo (2022) reported that chitosan-coated strawberries exhibited approximately 40–55% lower weight loss and maintained significantly higher firmness compared to untreated fruit during 10–14 days of cold storage. Similarly, Santika et al. (2020) observed that chitosan treatment reduced microbial growth by nearly 2–3 log CFU g^{-1} relative to control samples.

In the present study, the coated strawberries showed a 55.8% lower cumulative weight loss and a reduction of more than 4 log CFU g^{-1} in total microbial count compared to the control on Day 12, indicating that the effectiveness of the coating system is comparable or superior to those previously reported. These results further confirm that biopolymer-based edible coatings function as effective physical barriers that restrict mass transfer of water vapor and respiratory gases, leading to reduced respiration rate and delayed senescence.

From a practical perspective, the successful preservation of key color attributes (L^* and α^*) and microbial stability directly enhances consumer acceptance, marketability, and commercial shelf life of fresh strawberries. Considering that postharvest losses due to wilting and discoloration remain a major constraint in strawberry distribution, especially in developing cold chain systems, the application of chitosan coating offers a low-cost, environmentally sustainable solution that can reduce dependence on synthetic chemical preservatives.

Future Research Directions

While the effectiveness of the current coating formulation in color maintenance is clearly established, subsequent research efforts should strategically concentrate on the following areas:

- Coating Formulation Optimization: The incorporation of natural antimicrobial and antioxidant agents (such as cinnamon, clove, or plant phenolic extracts) into the chitosan matrix should be explored to establish a dual-function coating that simultaneously preserves color quality and enhances antifungal activity, particularly toward *Botrytis cinerea*.

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- Sensory and Consumer Correlation: Comprehensive sensory evaluation involving visual appearance, aroma, texture, and overall acceptability should be conducted to directly correlate instrumental CIELAB color parameters with actual consumer perception and purchasing preference.
- Economic Feasibility Assessment: Detailed techno-economic assessment and large-scale application studies (dipping vs. spraying systems) are required to evaluate the industrial feasibility and cost-effectiveness of this coating technology for commercial strawberry postharvest handling.

5. Conclusions

Conclusion of the Study

This study demonstrated the significant efficacy of chitosan-based edible coating in preserving the physical, chemical, and microbiological quality of strawberries during 12 days of cold storage. The coating application effectively retarded the decline in lightness (L*) and controlled the development of redness (a*), thereby maintaining color attributes that are critical for consumer acceptance. In addition, the coated fruit exhibited lower weight loss, higher firmness, better vitamin C retention, and significantly reduced microbial growth compared to the untreated control.

The L* values remained statistically higher in the coated strawberries at the end of storage, confirming that the coating acts as an effective moisture and oxygen barrier, thereby mitigating both water loss-induced wilting and enzymatic browning. Overall, these findings establish that chitosan-based edible coating represents a viable, practical, and environmentally friendly postharvest technology for extending the commercial shelf life of highly perishable non-climacteric fruits such as strawberries.

Research Limitation

Although this study comprehensively evaluated physical (weight loss, firmness, color), chemical (TSS, TTA, pH, vitamin C, antioxidant activity), and microbiological (TPC, yeast and mold) parameters, several limitations remain. Sensory attributes such as aroma, taste, texture perception, and overall consumer acceptance were not assessed. In addition, volatile compound profiling, which plays a key role in flavor quality, was not included. These aspects should be considered in future studies to

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complement the instrumental quality measurements and provide a more complete assessment of market acceptability.

Suggestions and Recommendations

Based on the research implications and limitations identified, the following recommendations are proposed for future investigations:

- Integrated Sensory and Instrumental Quality Assessment: Future studies should integrate sensory evaluation with physical, chemical, and microbiological analyses to ensure that the instrumental improvements observed (color, firmness, and nutritional quality) are aligned with consumer preferences and acceptance.
- Enhancing Coating Functionality: The incorporation of specific bioactive agents, such as natural essential oils or plant-derived phenolic extracts, into the chitosan matrix should be explored to enhance antimicrobial and antioxidant properties, particularly for the control of mold and yeast growth, which are major contributors to late-stage spoilage.
- Cost-Benefit and Scalability Analysis: To facilitate technology transfer from laboratory to commercial practice, future research should focus on detailed economic feasibility studies, optimization of application methods (dipping versus spraying), and evaluation of large-scale industrial scalability of the coating process.

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