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Comparative evaluation of *Aloe vera* and chitosan edible coatings on shelf life and quality of strawberries during cold storage

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Abstract: Strawberries (*Fragaria × ananassa* Duch.) are nutrient-rich specialty fruits with a short shelf life due to microbial spoilage, softening, darkening, and moisture loss. This study aimed to investigate the effectiveness of edible coatings in extending shelf life and maintaining fruit quality. Freshly ripened, randomly selected strawberries were coated with 1.5% chitosan, 1.5% chitosan+1% $CaCl_2$, *Aloe vera* gel (AVG), and AVG+1% $CaCl_2$, along with an uncoated control. Each treatment was replicated 3 times with 25 samples per replicate, followed by air drying. The coated strawberries were stored in sterilized polypropylene containers under standard refrigerated conditions (4±1°C; 50±5% relative humidity) for 9 days. The application of edible coatings significantly ($p<0.05$) reduced respiration rates (by 25 to 34%) and microbial load (by 41 to 62%), helping to preserve fruit color, moisture content, ascorbic acid, firmness, and overall acceptability. The effect was more pronounced in strawberries coated with AVG and AVG+1% $CaCl_2$ coatings on strawberries throughout storage period. Uncoated strawberries had an acceptability score of 4.0, while all coated fruits scored above 5, showing a significant improvement by 20 to 37%. Strawberries treated with AVG, with or without $CaCl_2$, maintained the highest acceptability score of 5.5, outperforming all other coatings. These findings suggest that *Aloe vera*-based coatings are particularly effective in extending the shelf life and preserving the quality of strawberries during refrigerated storage.

1. Introduction

Strawberries (*Fragaria × ananassa* Duch.) are among the most widely

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consumed specialty fruits worldwide, prized for their vibrant color, distinct flavor, sweet-tart taste, and high nutritional value. The global demand for strawberries continues to rise with worldwide production reaching 40.8 million tons in 2020 (FAO, 2022). Their versatility culinary applications - from fresh consumption to processed products such as jams, jellies, beverages, dairy items, and flavored drinks - makes strawberries one of the most widely used and adaptable crops in the world (Wise *et al*., 2024).

Rich in vitamins, minerals, flavonoids, anthocyanins, proteins, and phenolic compounds (Temiz and Ozdemir, 2021), strawberries offer numerous health benefits. However, their delicate texture and high respiration rate significantly reduce their shelf life. As a result, strawberries are highly susceptible to bruising, moisture loss, discoloration, microbial spoilage, and softening (Nasrin *et al.,* 2017).

To maintain fruit quality, strawberries should be rapidly chilled and stored at low temperatures (0-4°C) immediately after harvest. However, even with proper cold storage, their shelf life typically remains limited to less than five days (Shankar *et al.,* 2021). To further reduce postharvest losses and extend shelf life, several complementary strategies have been investigated, including active packaging, modified atmosphere packaging, and the use of edible coatings (Zhang *et al.,* 2022).

Among the emerging postharvest preservation techniques, edible coatings have attracted considerable attention in the fruit and vegetable industry for their proven effectiveness in preserving quality and prolong shelf life (Sousa Cesar de Albuquerque *et al.,* 2024). These coatings act as physico-chemical barriers, protecting against microbial contamination and water loss while preserving texture, color, flavor, and volatile compounds. Additionally, they help reduce respiration and transpiration rates, thereby delaying senescence (Nasrin *et al.,* 2023). Polysaccharide-based coatings are particularly valued for their excellent film-forming ability, mechanical strength, and selective permeability - especially in regulating oxygen exchange (Rios *et al.,* 2022).

Aloe vera gel (AVG) is an increasingly recognized edible coating material, primarily due to its high polysaccharide and soluble sugar content, which aids in preserving fruit quality by regulating water and oxygen exchange. This regulation helps lower respiration rates and maintain the fruit's texture, moisture content, color, taste, and firmness (Sogvar *et al.,* 2016; Nicolau-Lapena *et al.,* 2021). AVG is colorless, tasteless, and does not alter the sensory attributes of coated fruits (Hasan *et al.,* 2021). Moreover, it contains more than 200 bioactive compounds with antioxidant, antiviral, and antibacterial properties (Nguyen *et al.,* 2020). Beyond extending shelf life, AVG coatings also offer the potential to enhance the functional qualities of fruits through the incorporation of additional bioactive ingredients.

Due to excellent film-forming and antimicrobial properties, AVG is an effective edible coating that can be applied alone or in combination with other ingredients to extend the shelf life of a wide variety of fruits and vegetables, including lime (Pimsorn *et al.,* 2022), pistachio (Valverde *et al.,* 2005), apples (Ergun and Satici*,* 2012), guava (Shabir *et al.,* 2021), strawberries (Hassan *et al.,* 2022), and tomato (Chrysargyris *et al.,* 2016). Chitosan-based coatings have also demonstrated efficacy in reducing fungal decay, delay ripening and senescence, and maintaining the postharvest quality of fresh produce such as tomatoes, strawberries, and cherry tomatoes (Zheng *et al.,* 2024).

Similarly, calcium chloride ($CaCl_2$) applications have demonstrated benefits such as improved fruit firmness, enhanced antioxidant activity, reduced disease incidence, and mitigation of physiological disorders like internal browning and senescence (Nguyen *et al.,* 2020). However, there is limited information on the combined effects of AVG or chitosan with $CaCl_2$ on the postharvest quality of strawberries.

This study tests the hypothesis that AVG, either alone or in combination with $CaCl_2$, will enhance the postharvest quality and shelf life of strawberries more effectively than conventional chitosan-based coatings. By comparing key quality parameters such as firmness, microbial stability, moisture retention, and sensory acceptability, the study aims to determine the most effective edible coating strategy for maintaining strawberry freshness during storage.

2. Materials and Methods

Plant material

Freshly ripened strawberries (var. BARI Strawberry 3) were randomly harvested from the field plots of the Fruit Research Farm at the Horticulture Research Center (HRC), Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh.

A total of 375 strawberries were selected based on uniform size, absence of microbial infection or physical damage, and having more than 80% red surface area. *Aloe Vera* leaves were sourced from the Flower Research Farm of HRC at BARI, Gazipur.

Edible coating formulations

High molecular weight chitosan-652 was procured from Mahtani® Chitosan Pvt. Ltd., India was used to prepare a 1.5% chitosan solution, by dissolved 1.5 g of chitosan in 75 mL of distilled water, followed by the addition of 2 mL of reagent-grade acetic acid. The mixture was warmed to 55±2°C and stirred continuously to ensure homogeneity. A 2M NaOH solution was then added to adjust the pH to 5.6. Sterilized distilled water was subsequently added to bring the final volume to 100 mL (Jiang and Li, 2001). To prepare the 1.5% chitosan+1% $CaCl_2$ solution formulation, 1 g of $CaCl_2$ was added to the 1.5% chitosan solution and thoroughly stirred.

Mature *Aloe Vera* leaves were washed with a 25% aqueous chlorine solution. The outer layer was removed to extract the clear, water-based gel (lymph), which was ground and filtered to remove fibers. The gel was pasteurized at 70°C for 45 min and then cooled to room temperature (~25 °C). To stabilize the pH at ~4.0, ascorbic acid (2.0 g L^{-1}) and citric acid (4.5 g L^{-1}) were added. To enhance viscosity and coating performance, 1% sodium carboxymethyl cellulose (CMC), a natural cellulose-based gelling agent, was incorporated and thoroughly mixed. The solution was stored in an opaque glass container to prevent oxidation (Nasrin *et al.,* 2017). For another formulation, 1 g of $CaCl_2$ was added to the AVG solution and thoroughly mixed to obtain the AVG+1% $CaCl_2$ solution.

Experiment and coating application

The experiment was conducted using a completely randomized design (CRD) under controlled laboratory conditions, with 75 strawberries assigned to each coating treatment. Five coating treatments were evaluated: (1) control (no coating), (2) 1.5% chitosan solution, (3) 1.5% chitosan + 1% $CaCl_2$ solution, (4) AVG, and (5) AVG + 1% $CaCl_2$ solution. Each treatment was replicated three times, with 25 randomly selected fresh strawberries per replicate.

Strawberries were immersed in the respective coating solutions for one minute, then air-dried using a high-speed fan. Following drying, the fruits were stored in clear polypropylene containers at 4±1°C and 50±5% relative humidity in an incubator. Selected chemical, physical, and sensory attributes were assessed at harvest (day 0) and after 3, 6, and 9 days of storage.

Chemical and physical properties of strawberries

Respiration rate

For respiration rate measurement, 10 fruits from each replication were used. Throughout the storage period, respiration rates were recorded at designated intervals. Fruits from each replication were placed in a 1000 mL airtight jar sealed with septa and incubated at 20±2°C for two hours. After incubation, a 1 mL gas sample was extracted from the headspace of the jar using a syringe and analyzed with a CO_2/O_2 gas analyzer (Quantek® Instruments, Model 902D, USA). The concentration of CO_2 produced within the jar was recorded. Respiration rate was then calculated using the total gas volume of the jar, the weight and volume of the strawberries, and the incubation time. Results were expressed as mL CO_2 kg^{-1} h^{-1} (Nasrin *et al.,* 2020).

Firmness

Three fruits from each replication were used to evaluate strawberry firmness using a Fruit Texture Analyzer (GUSS®, Model GS25, SA). A stainless-steel flat-headed probe with an 8 mm diameter penetrated the fruit at a speed of 5 mm s^{-1}. Firmness was defined as the maximum force required to penetrate the fruit tissue. Following zero-force contact between the probe and the horizontally positioned strawberry, the equatorial region of each fruit was tested at two evenly spaced points, with 3 mm penetration depth. Data analysis was based on the maximum force recorded during probe movement, with results expressed in Newtons (N).

Weight (moisture) loss

Strawberry weight loss (moisture content) was measured using 10 fruits from each replication at the start of the experiment - immediately after the surface coating was applied and dried - and subsequently at three-day intervals throughout the storage period. Weight loss was computed by using the following equation and then displaying the result as a percentage.

Weight loss (%) = (Initial fruit weight -Final fruit weight at indicated period)/(Initial fruit weight) x100

External fruit color

Surface color of strawberries was measured on five fruits from each replication using a Chroma Meter (Model CR-400, Minolta Corp., Japan) based on the CIE Lab* system. Here, L* denotes lightness, while a* and b* values were used to calculate Chroma (c) and hue angle (h°). The instrument was calibrated with the provided white tile before measurement. Multiple readings were taken from different areas of each fruit.

After measuring respiration rate, weight loss, and color, the fruits were returned to refrigeration to continue the experiments and assess shelf life.

Ascorbic acid, titratable acidity, and sugar

Ascorbic acid, titratable acidity, total sugar, and reducing sugar concentrations were analyzed following AOAC (1994) standard methods. Total soluble solids (TSS) were measured using a refractometer, and the pH of strawberry juice was determined using a pH meter (HANNA® Instruments, pH-211; Microprocessor pH Meter, Italy).

Ascorbic acid concentration in strawberry juice was determined using a titration method with 2,6-dichlorophenolindophenol (DCPIP) dye. In this method, ascorbic acid in an alkaline medium reduces the blue-colored DCPIP dye to a colorless form. The dye solution was first standardized against known concentrations of ascorbic acid to determine the dye factor. For analysis, strawberry juice was diluted with 3% metaphosphoric acid and then titrated with the DCPIP solution until a persistent pink endpoint lasting 15 seconds was observed.

Dye factor= 0.5/(Titrate volume)

Ascorbic acid (mg/100g) = (Titre x Dye factor x Volume x 100)/(Aliquot of extract taken x Weight of sample)

Titratable acidity was determined by blending 10 g of strawberries with 100 mL of distilled water, followed by filtration of the mixture. Three to four drops of phenolphthalein indicator were then added, and the filtrate was titrated with 0.1 M NaOH. The titratable acidity was calculated using the following formula:

Titratable acidity (%) = [(titre vol.× normality of NaOH × vol.made up × eq.wt.of acid)/(aliquot of sample × vol. of sample × 1000)] x100

Total soluble solids were measured using a hand-held refractometer (Atago® MASTER-53α, Japan) and expressed in °Brix. A small volume of strawberry juice was placed on the prism surface of the refractometer, and the TSS value in °Brix was recorded directly from the instrument's display

Microbiological analysis of strawberries

A 10 g sample of fresh strawberries were thoroughly combined with 90 mL of sterilized 0.9% NaCl solution. The homogenized sample was included in 1 ml to the corresponding dilutions (10^{-1} to 10^{-6}) applying a 0.9% sodium chloride solution. Total bacterial count (TBC) was measured using nutrient agar (DifcoTM, USA, H 7.0-7.4), while molds as well as yeast were counted using potato dextrose agar (PDA, HiMedia, India). The media was made as directed by the manufacturer. Inoculated nutrient agar media plates underwent incubation for 24 to 28 hours at 37°C, while plates with PDA were kept for 5 days at room temperature (26 ± 2°C). Plates showing colonies were examined after incubation. TBC was calculated by multiplying the dilution factor by the average number of colonies in a given dilution. Colony forming units per gram (cfu/g) were used to represent the microorganisms present in the samples (Mahfuza *et al.,* 2016).

Sensory quality

Sensory quality of fresh strawberries was assessed by 15 trained panelists (aged 25-50 years, both male and female). The panel evaluated the samples based on color, flavor, texture, and overall acceptability. Prior to the evaluation, panelists underwent pre-training focused on strawberry appearance, aroma, and taste. For each treatment, three samples were evaluated per panelist in a randomized order. Samples were blindly labeled using random three-digit codes to minimize bias. To cleanse their palate between samples, panelists rinsed their mouths with plain water.

Evaluations were conducted using a 9-point hedonic scale ranging from 1 to 9, where: 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, and 9 = like extremely (Nasrin and Anal, 2015). A score of 5 ("neither like nor dislike") was used as the cutoff point for consumer acceptability.

Statistical analysis

Data were analyzed using a two-way analysis of variance (ANOVA) based on a CRD to assess the effects of different coating treatments and storage time on various quality parameters of strawberries. The ANOVA was conducted using SAS® software (version 9.2, 2010), with coating treatment considered a fixed effect and time treated as a random effect to account for temporal variation. The model evaluated the main effects and interactions on dependent variables such as firmness, color, weight loss, TSS, acidity, pH, total sugar, reducing sugar, flavor, texture, and overall acceptability. The Least Significant Difference (LSD) test was used to compare treatment means, with significance set at $p \leq 0.05$ unless otherwise noted. Graphical representations and regression analyses were performed using SigmaPlot® software.

3. Results

Respiration rate

The initial respiration rate of strawberries was 63 mL kg^{-1} h^{-1}, which was significantly and non-linearly reduced by nearly half when coated with either AVG alone ($y = 61.6 - 9.61*X + 0.79*X^2$) or AVG with 1% $CaCl_2$ ($y = 61.7 - 9.83*X + 0.79*X^2$), accounting 93 and 94% of the variation in respiration rates during storage, respectively (Fig. 1). In uncoated control strawberries, respiration rate began increasing significantly from the 3rd day, while in coated samples, it started to rise slightly only after the 6th day ($y = 33 + 30.3^{(-0.56*X) + 2.35*X}$). By the 9th day, the highest respiration rate (54.3 mL kg^{-1} h^{-1}) was observed in the uncoated control strawberries, whereas the lowest (35.6 mL kg^{-1} h^{-1}) was recorded in strawberries coated with AVG+1% $CaCl_2$. However, no significant differences were found among the coated treatments.

Fruit firmness

The initial firmness of the strawberries was 2.42 N, which declined significantly and linearly over time; however, the rate of softening varied among the coating treatments (Fig. 2). Strawberries coated with AVG+1% $CaCl_2$ retained the highest firmness ($y = 2.47 - 0.05*X$) explaining 86% of the variability in firmness. These strawberries lost only 20.2% of their initial firmness by day 9. In contrast, uncoated control strawberries exhibited the greatest decline in firmness ($y = 2.31 - 0.12*X$), showing a 47% reduction over the same period.

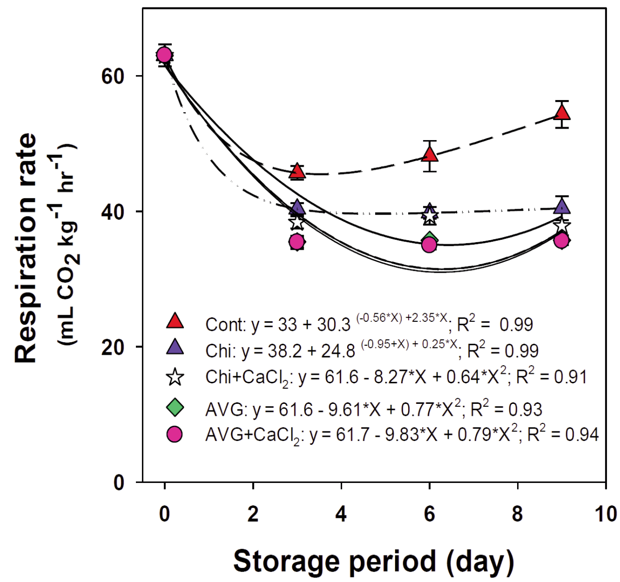

Fig. 1 - Effects of various edible coatings on respiration rates (mL CO_2 kg^{-1} h^{-1}) of strawberries during storage at 4±1°C Control= Uncoated, Chi= 1.5% chitosan coated, Chi+$CaCl_2$= 1.5% chitosan +1% $CaCl_2$ coated, AVG= *Aloe vera* gel coated, AVG+$CaCl_2$= AVG+1% $CaCl_2$ coated. Data presented with standard error of mean.

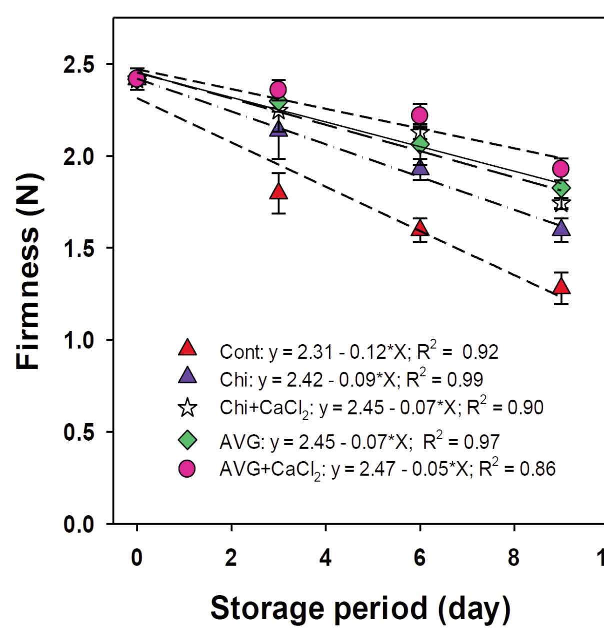

Fig. 2 - Effects of various edible coatings on firmness (N) of strawberries during storage at 4±1°C [Control= Uncoated, Chi= 1.5% chitosan coated, Chi+$CaCl_2$= 1.5% chitosan + 1% $CaCl_2$ coated, AVG= *Aloe vera* gel coated, AVG+$CaCl_2$= AVG+1% $CaCl_2$ coated. Data presented with standard error of mean.

Weight (moisture) loss

Uncoated control strawberries exhibited the highest linear weight (moisture) loss during storage (y = 0.08 + 0.97*X) compared to coated strawberries (Fig. 3). Coating with 1.5% chitosan, either with (y = 0.30 + 0.64*X) or without 1% $CaCl_2$ (y = 0.20 + 0.67*X) significantly reduced weight loss to approximately ~ 6%. In contrast, strawberries coated with AVG, with (y = 0.17 + 0.55*X) or without 1% $CaCl_2$ (y = 0.13 + 0.53*X), exhibited the lowest weight loss—around 5%—relative to the uncoated control.

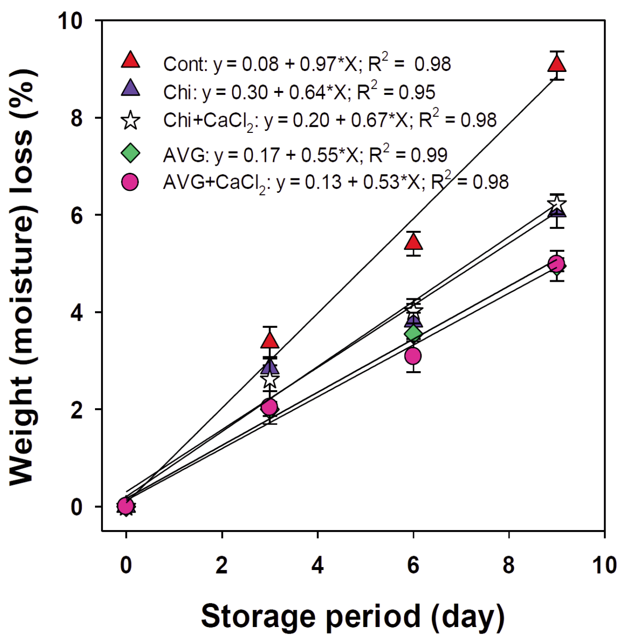

Fig. 3 - Effects of various edible coatings on weight (moisture, %) loss of strawberries during storage at 4±1°C. Control= Uncoated, Chi= 1.5% chitosan coated, Chi+$CaCl_2$= 1.5% chitosan +1% $CaCl_2$ coated, AVG= *Aloe vera* gel coated, AVG+$CaCl_2$ = AVG+1% $CaCl_2$ coated. Data presented with standard error of mean.

External fruit colour

Throughout storage, uncoated control strawberries appeared darker than coated ones (Fig. 4a). Among coatings, AVG-treated strawberries exhibited a brighter red color than those with chitosan. The addition of 1% $CaCl_2$ improved lightness in both coatings. By day nine, the lightness (L*) value declined significantly and linearly in uncoated control fruits (y = 40 – 1.28X), with a 29.5% reduction, compared to 14.7% for chitosan + $CaCl_2$ (y = 40.4 – 0.59X) and 11.7% for AVG + $CaCl_2$ (y = 40.8 – 0.53*X), explaining 99% of color variation.

The hue angle (h°) of uncoated control strawberries began decreasing after day two (y = 36 – 0.66X – 0.035X²), dropping by 24.2% by day six (Fig. 4b). In contrast, coated fruits maintained a stable hue angle until day six, followed by a slight decline. On day nine, the lowest hue angle (27.3) was recorded in the uncoated control, while the highest

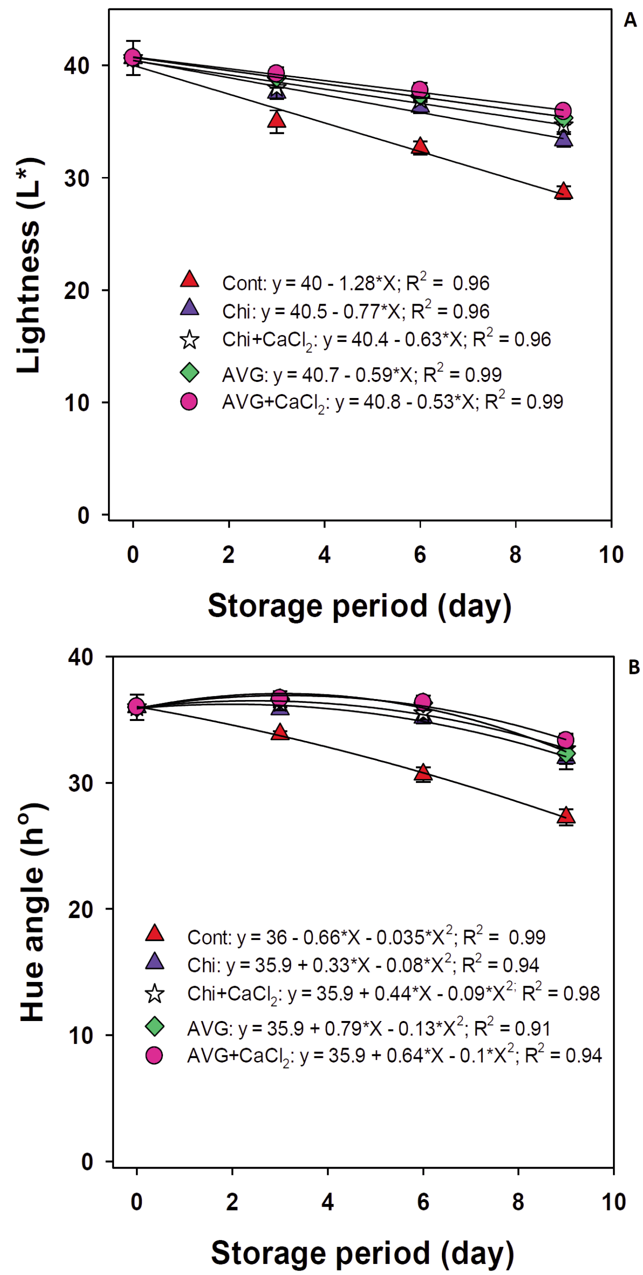

Fig. 4 - a) Effects of various edible coatings on external fruit colour evolution (lightness, L*) of strawberries stored at 4±1°C. b) Effects of various edible coatings on external fruit colour evolution (hue angle, ho) of strawberries stored at 4±1°C Control= uncoated, Chi= 1.5% chitosan coated, Chi+$CaCl_2$= 1.5% chitosan +1% $CaCl_2$ coated, AVG= *Aloe vera* gel coated, AVG+$CaCl_2$= AVG+1%$CaCl_2$ coated. Data presented with standard error of mean.

(33.3) was observed in AVG+$CaCl_2$-coated strawberries ($y = 35.9 + 0.64X - 0.1X^2$).

Ascorbic acid, titratable acidity, and sugar

At the beginning of storage, the ascorbic acid, titratable acidity, and pH of strawberries were 47.8 mg 100 g^{-1}, 0.86%, and 3.94, respectively (Table 1). By the ninth day, the ascorbic acid concentration in control fruits had significantly decreased to 35.6 mg/100 g. In contrast, strawberries coated with AVG+1% $CaCl_2$ maintained the highest ascorbic acid concentration at 44.9 mg 100 g^{-1}, which was significantly higher than that of both the control and other coated treatments. Although titratable acidity declined and pH slightly increased by day nine, these changes were not statistically significant among the different coating treatments (Table 1).

Regarding sugar content, initial values for TSS, total sugars, and reducing sugars in fresh strawberries were 7.5°Brix, 5.4%, and 4%, respectively (Table 1). All these values increased by day nine. However, there were no significant differences in total and reducing sugar contents among the treatments. The highest TSS (9.4°Brix) was observed in the control (uncoated) strawberries, whereas significantly lower TSS values (8.3°Brix) were recorded in strawberries coated with AVG, either alone or combined with $CaCl_2$. There were no significant differences in TSS among the coated fruits.

Microbiological analysis

Although coating treatments initially caused a non-significant reduction in total bacterial count (TBC), microbial loads increased non-linearly over time from a baseline of 2.11 log CFU g^{-1} (Fig. 5). Strawberries coated with AVG, with ($y = 2.08 - 0.64X$

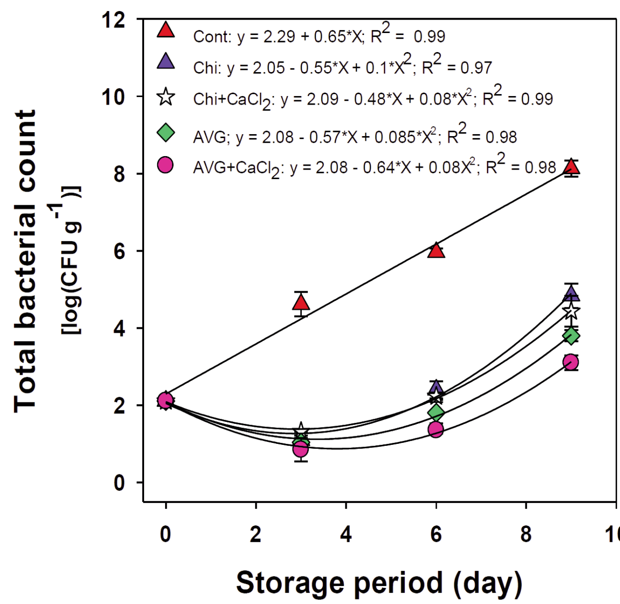

Fig. 5 - Effects of various edible coatings on total bacterial count (log CFU g^{-1}) of strawberries during storage at 4±1°C Control= uncoated, Chi= 1.5% chitosan coated, Chi+$CaCl_2$= 1.5% chitosan +1% $CaCl_2$ coated, AVG= *Aloe vera* coated, AVG+$CaCl_2$= AVG+1% $CaCl_2$ coated. Data presented with standard error of mean.

Table 1 - Effect of various edible coatings on biochemical properties (ascorbic acid, acidity, pH, total soluble solids, total sugar, and reducing sugar) of strawberries stored in the refrigerator (at 4±1°C) over a nine-day period

Coating treatments	Day	Ascorbic acid (%)	Acidity (%)	pH	TSS (%)	Total sugar (%)	Reducing sugar (%)
Control	0	47.8	0.86	3.94	7.5	5.4	4.0
	9	35.6	0.73	3.99	9.4	5.6	4.2
Chi	0	47.8	0.86	3.94	7.5	5.4	4.0
	9	41.6	0.74	3.97	8.6	5.5	4.1
Chi+$CaCl_2$	0	47.8	0.86	3.94	7.5	5.4	4.0
	9	41.5	0.77	3.97	8.5	5.5	4.1
AVG	0	47.8	0.86	3.94	7.5	5.4	4.0
	9	42.1	0.75	3.96	8.3	5.5	4.0
AVG+$CaCl_2$	0	47.8	0.86	3.94	7.5	5.4	4.0
	9	44.9	0.77	3.95	8.3	5.4	4.0
$LSD_{p≤0.05}$							
Coating		2.66	0.02 NS	0.02 NS	0.28	0.23 NS	0.12 NS
Time		1.68	0.01	0.01	0.18	0.14 NS	0.08
Coating x time	1.20	0.01 NS	0.01 NS	0.13	0.10 NS	0.05 NS	

Control= Uncoated, Chi= 1.5% chitosan coated, Chi+$CaCl_2$ = 1.5% chitosan +1% $CaCl_2$ coated, AVG= *Aloe vera* gel (AVG) coated, AVG+$CaCl_2$= Aloe vera gel (AVG)+1% $CaCl_2$ coated. TSS=Total soluble solids. Ns= Not significant.

+ 0.08X²) or without 1% $CaCl_2$ ($y = 2.08 - 0.57X + 0.085X^2$), showed significantly lower TBC compared to the uncoated control ($y = 2.29 + 0.65^*X$). By the end of storage, TBCs were 3.1 and 3.8 log CFU g^{-1} for AVG+$CaCl_2$ and AVG coatings, respectively, versus 8.13 log CFU g^{-1} for the control. AVG alone reduced microbial load by 4.33 log CFU g^{-1} (~53%), while the addition of $CaCl_2$ provided an incremental reduction of 0.7 log CFU g^{-1} (~9%). Notably, all coated strawberries, except the control, remained below the permissible microbial contamination limit throughout storage.

Sensory quality and its relationship with other properties

Throughout the storage period, all fruits regardless of coatings exhibited variations in sensory properties (Table 2 and Fig. 6). By the 7th day of storage, the uncoated control strawberries exhibited lower sensory scores, with color (4.1), flavor (4.3), texture (4.3), and overall acceptability (4.0), falling below the consumer acceptability threshold. In

Table 2 - Effects of various edible coatings on sensory quality of strawberries (color, flavor, texture and overall acceptability) during storage in the refrigerator (at 4±1°C) over a nine-day period

Coating	Day	Color	Flavor	Texture	Overall acceptability
Control	7	4.1	4.3	4.3	4.0
	9	3.0	3.1	2.6	2.5
Chi	7	5.5	5.3	5.8	5.5
	9	4.1	4.2	4.4	4.1
Chi+$CaCl_2$	7	5.5	5.0	5.9	5.8
	9	4.3	4.6	4.5	4.4
AVG	7	7.2	6.9	7.0	7.3
	9	5.8	5.9	5.1	5.5
AVG+$CaCl_2$	7	7.6	6.9	7.3	6.9
	9	5.6	5.5	5.5	5.5
LSD$_{p\leq0.05}$					
Coating		0.46	0.40	0.43	0.41
Time		0.29	0.25	0.27	0.26
Coating x time	0.19 NS	0.17 NS	0.18 NS	0.17 NS	

Control= Uncoated, Chi= 1.5% chitosan coated, Chi+$CaCl_2$= 1.5% chitosan +1% $CaCl_2$ coated, AVG= *Aloe vera* gel coated, AVG+$CaCl_2$= AVG+1% $CaCl_2$ coated. Ns= Not significant.

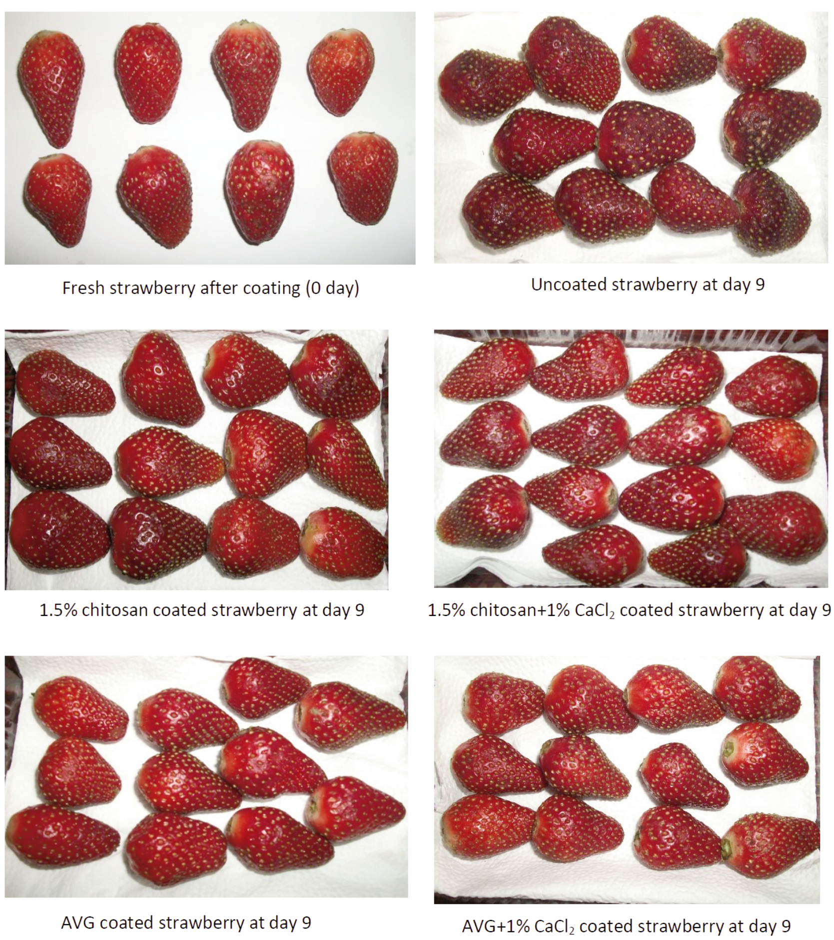

Fig. 6 - Visual appearance of post edible-coated strawberry treatments (control=uncoated, Chi= 1.5% chitosan, Chi+$CaCl_2$= 1.5% chitosan +1% $CaCl_2$, AVG= *Aloe vera* gel, AVG+$CaCl_2$= AVG+1% $CaCl_2$) for 9 days refrigerated storage at 4±1°C.

contrast, all coated strawberries-maintained scores above 5. Notably, strawberries coated with AVG, with or without $CaCl_2$, achieved higher sensory scores ranging from 6.9 to 7.6 and retained an average overall acceptability of 5.5 even by the 9th day of storage. Meanwhile, the sensory scores of strawberries coated with chitosan, with or without $CaCl_2$, declined below acceptable levels by the 9th day, with overall acceptability dropping below 4.5, once again falling beneath the consumer acceptance threshold.

Pearson correlation analysis of strawberry chemical, physical, and sensory attributes revealed that increased moisture loss was significantly and strongly correlated with reductions in firmness and pH, and moderately associated with decreases in reducing sugars, color, flavor, texture, and overall acceptability (Table 3). Firmness exhibited significant positive correlations with pH, reducing sugars, color, flavor, texture, and overall acceptability. Similarly, color showed significant positive correlations with flavor, texture, and overall acceptability, and these relationships were reciprocal. Total soluble solids (TSS) did not show significant correlations with any measured strawberry properties. In contrast, increasing ascorbic acid (vitamin C) content was positively correlated with total sugar concentration but negatively correlated with color, flavor, texture, and overall acceptability. Titratable acidity was significantly negatively correlated with both total and reducing sugar concentrations.

4. Discussion and Conclusions

Respiration rate

A significant reduction in respiration rates of strawberries was due to AVG coatings with or without $CaCl_2$ was beneficial as the elevated respiration rates accelerate carbohydrate depletion, leading to faster deterioration of fruit quality and reduced shelf life (Nasrin *et al.,* 2022). AVG coatings, especially when combined with $CaCl_2$, can significantly influence fruit gas exchange possibly causing saturation effects (Valverde *et al*., 2005). $CaCl_2$ enhances the structural stability of AVG and introduces Ca ions that may interact with *Aloe vera* polysaccharides and phenolics, altering viscosity, film properties, and antimicrobial activity (Shabir *et al.*, 2021). These interactions results in decreased respiration, ethylene production, transpiration, mechanical damage, and microbial growth (Blancas-Benitez *et al.,* 2022). Shafique *et al.* (2023) reported that strawberries coated with 20% AVG showed a two-fold reduction in respiration rate at five days of shelf life, when compared to control ones. Furthermore, Eshghi *et al.* (2014) observed significantly lower respiration rates in strawberries coated with nano-chitosan compared to uncoated control ones.

Fruit firmness

As anticipated, strawberries coated with AVG exhibited the highest firmness, primarily due to the

Table 3 - Pearson correlations among strawberry chemical, physical, and sensory properties

	Firmness	Respirative rate	Total soluble solids	pH	Ascorbic acid	Titrable acid	Total sugar	Reducing sugar	Color	Flavor	Texture	Acceptability
Moisture	-0.95 ***	-0.51 *	0.23 NS	-0.88 ***	0.25 NS	0.63 **	-0.45 *	-0.69 **	-0.48 *	-0.46 *	-0.53 *	-0.50 *
Firmness		0.32 NS	-0.29 NS	0.85 ***	-0.48 *	-0.48 *	0.24 NS	0.67 **	0.58 *	0.56 *	0.63 **	0.61 **
Resp			0.21 NS	0.49 *	0.27 NS	-0.66 **	0.60 *	0.30 NS	0.01 NS	-0.06 NS	0.06 NS	0.07 NS
TSS				-0.23 NS	0.26 NS	-0.09 NS	0.12 NS	0.11 NS	-0.26 NS	-0.23 NS	-0.29 NS	-0.21 NS
pH					-0.25 NS	-0.53 *	0.31 NS	0.66 **	0.25 NS	0.21 NS	0.33 NS	0.28 NS
Aacid						-0.3 2 NS	0.63 **	-0.2 2NS	-0.67 **	-0.68 **	-0.64 **	-0.68 **
Tacid							-0.87 ***	-0.64 **	0.17 NS	0.19 NS	0.12 NS	0.16 NS
Tsugar								0.35 NS	-0.36 NS	-0.36 NS	-0.31 NS	-0.34 NS
Rsugar									0.15 NS	0.16 NS	0.19 NS	0.19 NS
Color										0.99 ***	0.97 ***	0.98 ***
Flavor											0.94 ***	0.97 ***
Texture												0.98 ***

*, **, and *** indicate significant correlations at $p<0.05$, 0.01, and 0.001 levels, respectively.
NS = Not significant.

preservation of polysaccharide structures that enhance cell wall strength. Fruit softening typically occurs during development, ripening, and senescence, driven by water loss and the degradation of structural components through respiration. However, AVG helps mitigate these effects by forming a protective physical barrier that reduces water evaporation and maintains the integrity of the fruit's dry matter content, thereby slowing the softening process and extending postharvest quality (Nasrin *et al*., 2023).

The AVG + 1% $CaCl_2$ coating was particularly effective in reducing fruit softening by inhibiting enzyme activity, especially polygalacturonase, which breaks down cell walls during ripening. Additionally, their synergistic effects limit oxygen uptake, moisture loss, microbial growth, and metabolic activity, thereby delaying ripening and preserving firmness in strawberries (Rehman *et al*., 2022).

Calcium contributes further by strengthening cell walls and enhancing tissue firmness through pectin formation (White and Broadley, 2003). Additionally, a 1.5% chitosan coating - with or without $CaCl_2$ - has been shown to better maintain strawberry firmness than a 1% $CaCl_2$ dip over a 4-day storage period at 20°C (Hernandez-Munoz *et al*., 2006).

Weight (moisture) loss

Weight (moisture) loss in strawberries increases susceptibility to shrinkage, skin wounding, softening, deterioration, and color darkening. The extent of moisture loss is largely influenced by the gradient in atmospheric pressure between the internal fruit tissues and the surrounding environment. Coating treatments, such as AVG and chitosan, effectively reduce this gradient by forming semi-permeable barriers that minimize transpiration, regulate gas exchange, and retain cellular moisture. The hygroscopic nature of AVG further enhances its ability to prevent water transfer between the fruit and its surroundings (Valverde *et al*., 2005).

Studies have reported that AVG coatings significantly reduce water vapor transmission rate and moisture loss in perishable fruits compared to untreated controls (Olivas and Barbosa-Cánovas, 2005). Likewise, Hassan *et al.* (2022) reported that uncoated strawberries exhibited the highest weight loss (11.9%), while those coated with 40% AVG + 1% lemongrass essential oil showed the lowest (6.1%), followed by 20% AVG + 1% lemongrass essential oil (7.6%) after 16 days of storage at 5 ± 1°C. Similarly, Nguyen *et al.* (2020) demonstrated that a coating of 0.2% nano-chitosan combined with 3% $CaCl_2$ was more effective in reducing weight loss than nano-chitosan alone or uncoated controls. This improvement is likely due to calcium's role in modifying tissue gas diffusion rates and affecting respiratory metabolism.

Overall, the reduced moisture loss in coated strawberries helps maintain fruit weight, limits respiration, delay senescence, and enhance postharvest shelf life by slowing physiological processes associated with deterioration.

External fruit colour

Coating fruits with AVG creates a modified environment that helps prevent chlorophyll degradation and carotenoid pigment synthesis, thereby delaying ripening (Ergun and Satici, 2012). Similarly, chitosan coatings have been shown to slow respiration and reduce ethylene production in papaya, resulting in delayed ripening and senescence, along with reduced softening and color changes (Ali *et al.*, 2011). In strawberries, uncoated fruits showed approximately a 29% reduction in lightness, whereas fruits coated with 1%, 1.5%, and 2% chitosan exhibited lightness losses of around 16%, 11%, and 10%, respectively. Enzymatic browning, primarily driven by the oxidation of polyphenolic compounds catalyzed by polyphenol oxidase (PPO), remains a major postharvest issue in strawberries (Kebriti *et al.*, 2025). However, strawberries coated with AVG showed only a 4% loss in lightness, likely due to the inhibition of PPO activity (Nasrin *et al.*, 2017). This suppression of enzymatic browning helps preserve the fruit's color and overall quality during storage.

Moreover, strawberries coated with AVG alone or in combination with lemongrass essential oil retained their lightness more effectively and maintained visual quality up to 16 days at 5°C (Hassan *et al.*, 2022). Treatments combining 40% AVG + 1% lemongrass essential oil and 20% AVG + 1% lemongrass essential oil also preserved higher hue angle values than the control during eight days of storage at 5°C. Additionally, Amal *et al.* (2010) found that strawberries coated with soy or gluten films incorporating thymol, as well as soy-based coatings containing $CaCl_2$, exhibited brighter red coloration and higher chroma values compared to uncoated fruits.

Ascorbic acid, titratable acidity, and sugar

The reduced loss of ascorbic acid (vitamin C) in coated strawberries is attributed to the protective effect of the edible coating, which limits oxygen exposure and slows respiration, thereby minimizing oxidative degradation (Ayranci and Tunc, 2004). Additionally, $CaCl_2$ has been shown to inhibit antioxidant loss, including that of ascorbic acid (Luna-Guzman and Barrett, 2000). Our findings align with those of Muzzaffar *et al*. (2016), who reported initial values for ascorbic acid, TSS, acidity, total sugars, and reducing sugars in fresh strawberries as 38.6 mg 100 g^{-1}, 8 °Brix, 1.3%, 5.2%, and 4.3%, respectively.

Similarly, Shabir *et al*. (2021) observed that during storage, fruit pH and TSS increased, while ascorbic acid and titratable acidity decreased. These changes were attributed to moisture loss through respiration and transpiration, starch breakdown, and the synthesis of pectin and free acids. Hassan *et al*. (2022) further confirmed that pH levels gradually increased and titratable acidity declined due to the oxidation of organic acids during ripening.

Lower TSS in AVG-coated strawberries result from both reduced concentration effects and slowed metabolic changes. AVG coatings form a semi-permeable barrier that minimizes water loss, limiting the passive concentration of sugars typically seen in uncoated fruits during storage (Olivas and Barbosa-Cánovas, 2005; Nasrin *et al*., 2017). This barrier helps maintain fruit moisture, preventing the artificial TSS increase caused by dehydration. Simultaneously, AVG reduces respiration rates by restricting oxygen diffusion, thereby slowing ripening and metabolic activity (Valverde *et al.*, 2005; Rehman *et al.*, 2022). This delay in ripening impedes the enzymatic breakdown of complex carbohydrates into simple sugars by inhibiting enzymes like amylases and polygalacturonases (Hassan *et al.*, 2022; Nicolau-Lapena *et al.*, 2021). Studies in guava and other fruits support this, showing that coated fruits accumulate sugars more slowly than uncoated controls (Ali *et al*., 2011; Rehman *et al*., 2022). Therefore, AVG-coated strawberries are expected to exhibit stable sugar concentrations over storage, avoiding the TSS spikes measured in uncoated fruit due to dehydration and accelerated metabolism.

Microbiological analysis

The reduction in total bacterial counts on of AVG and chitosan coated strawberries, with or without the addition of $CaCl_2$ is largely attributed to the complementary antimicrobial actions. AVG's efficacy stems from its bioactive compounds - primarily aloin and aloe-emodin - which inhibit fungal spore germination and suppress the growth of yeasts and molds (Huang and Yan, 2023). Moreover, AVG forms a semi-permeable barrier that reduces moisture loss, thereby limiting the water availability essential for microbial proliferation. $CaCl_2$ complements this effect by lowering cellular pH and water activity within the fruit's microenvironment, indirectly inhibiting microbial survival and possibly interfering with spore germination. Though $CaCl_2$ has limited direct action against spore-forming bacteria, it alters environmental conditions unfavorable for their growth. Coatings combining AVG with antimicrobial agents, such as lemongrass oil or $CaCl_2$, have demonstrated enhanced microbial suppression (Hassan *et al.*, 2022). In this study, AVG alone reduced microbial loads by ≈53%, while the addition of $CaCl_2$ resulted in an additional reduction of ≈9%. These results confirm that AVG is the primary antimicrobial agent, with $CaCl_2$ providing modest but synergistic enhancement, offering an effective strategy against postharvest spoilage, especially from yeasts, molds, and some bacteria.

Sensory quality and its relationship with other properties

Throughout the storage period, all fruits exhibited a decline in sensory properties, likely due to factors such as endogenous enzyme activity, skin darkening, and moisture loss (Badawy *et al.,* 2017). Our research aligns with the findings of Shabir *et al.* (2021), who reported that refrigerated fruits such as guavas coated with 10% AVG and 2% $CaCl_2$ achieved the highest overall acceptability score (6.18), compared to a score of 5.18 for uncoated fruits. Similarly, Pimsorn *et al.* (2022) observed that lime coated with AVG exhibited superior sensory and visual qualities, reduced weight loss, improved firmness, elevated ascorbic acid concentration and acidity, delayed increases in TSS, reduced decay, and extended shelf life compared to uncoated counterparts. Chrysargyris *et al.* (2016) found that tomatoes coated with 10% and 15% AVG and stored at 11 °C and 90% relative humidity maintained their overall quality by reducing ripening indices and ethylene production. Amiri *et al.* (2022) demonstrated that a coating formulation containing AVG, 2% $CaCl_2$, and 5% nano-encapsulated catechin significantly enhanced the quality and shelf life of refrigerated strawberries.

Pearson correlation analysis revealed that moisture loss was a key factor in strawberry quality decline, strongly negatively correlated with firmness and pH, and moderately with sugars, color, flavor, texture, and acceptability. Firmness showed strong positive correlations with nearly all quality traits, making it a reliable quality indicator. Color was also positively linked with key sensory attributes. Total soluble solids showed no significant associations, indicating stability during storage. Ascorbic acid correlated positively with total sugars but negatively with sensory traits, suggesting stress-related changes. Titratable acidity was negatively associated with sugars, reflecting ripening processes. Moisture retention and firmness are shown vital for shelf life.

This study demonstrated that uncoated strawberries retained acceptable quality for only 6 days, whereas those coated with 1.5% chitosan extended shelf life to 8 days. Notably, strawberries coated with AVG, with or without $CaCl_2$, maintained freshness for over 9 days, exhibiting superior firmness, color, moisture, and flavor, and texture retention, with no visible decay. Although the addition of $CaCl_2$ slightly enhanced firmness, moisture retention, and microbial suppression, these enhancements were not statistically significant. Interestingly, AVG alone provided sensory quality comparable to the AVG+$CaCl_2$ combination. These findings underscore AVG's strong potential as a natural, eco-friendly coating for extending strawberry shelf life and preserving nutritional quality, offering a sustainable alternative to synthetic packaging. Further research is recommended to investigate the phytochemical and metabolomic profiles, essential nutrient content, and cost-effectiveness to support broader commercial application.

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