



Chitosan and Plant Extract-Based Edible Coatings in Postharvest Life of Bell Pepper (*Capsicum Annuum* L.) Under Tropical Ambient Conditions

Amelita G. Alkuino^{1*}, and Al Emmanuel L. Caballes¹

¹ Cebu Technological University-Asturias Campus, Asturias, 6042 Cebu, Philippines

* Correspondence: amegatdula2197@gmail.com

Citation:

Alkuino, A.G.; Caballes, A.E.L. Chitosan and plant extract-based edible coatings in postharvest life of bell pepper (*Capsicum Annuum* L.) under tropical ambient conditions. *ASEAN J. Sci. Tech. Report.* **2026**, *29*(8), e265037. <https://doi.org/10.55164/ajstr.v29i8.265037>

Article history:

Received: April 17, 2026

Revised: May 31, 2026

Accepted: June 21, 2026

Available online: July 11, 2026

Publisher's Note:

This article is published and distributed under the terms of the Thaksin University.

Abstract: Growing concerns over food sustainability and postharvest losses have made eco-friendly preservation strategies essential. Edible coatings offer an alternative to refrigeration, helping maintain fruit quality during storage. This study evaluated chitosan and plant extract-based coatings on the postharvest quality of bell pepper under ambient conditions. The research was conducted in two phases. Study 1 tested chitosan at 1%, 2%, 3%, and 4% concentrations against an uncoated control, and Study 2 combined the most effective concentration with Aloe vera and Moringa leaf extracts. In Study 1, 2% chitosan was most effective in reducing weight loss and shriveling while maintaining firmness and visual quality. Building on this result, Study 2 applied five treatments: T0 (2% chitosan), T1 (50 mL of 2% chitosan + 50 mL of 50% Aloe vera), T2 (33 mL of 2% chitosan + 67 mL of 50% Aloe vera), T3 (50 mL of 2% chitosan + 50 mL of 50% Moringa leaf extract), and T4 (33 mL of 2% chitosan + 67 mL of 50% Moringa leaf extract). Among these, the Aloe vera-enriched coating T2 best reduced weight loss, delayed shriveling, and extended marketable shelf life, whereas the Moringa-chitosan treatments better preserved firmness but showed earlier visual deterioration. Overall, 2% chitosan alone delayed postharvest deterioration, but combining it with a higher proportion of Aloe vera was most effective, underscoring the potential of natural coatings as sustainable alternatives to refrigeration.

Keywords: Aloe vera gel; biodegradable packaging; moringa leaf extracts; sustainable food storage

1. Introduction

Food security is one of the major challenges we face worldwide. Millions of people around the globe still battle hunger and inadequate nutrition. Governments and the private sector address this issue by boosting local food production, but this is not sufficient because, in general, those commodities, especially horticultural crops, easily deteriorate after harvesting. Bell pepper (*Capsicum annuum* L.), a horticultural crop also known as sweet pepper, is considered an economically important crop due to its high nutritive value, as it is an excellent source of antioxidants, including carotenoids, ascorbic acid, flavonoids, and phenolic acids. These compounds contribute to its potential health benefits, including immune-modulatory effects, valuable antioxidant properties, and the potential to counteract carcinogenic processes [1]. Like most of the horticultural crops, postharvest losses of this crop account for about 40%

annually, and because bell peppers are highly perishable, once harvested, they continue to respire and transpire, resulting in moisture loss, shriveling, discoloration, and microbial spoilage, thus requiring meticulous handling and proper attention to retain their postharvest quality [2].

Over the past decades, numerous conventional methods have been developed for food preservation, but only a few strategies have been employed to extend the shelf life of bell peppers in a more natural, cost-effective, and sustainable way. Nowadays, consumers are becoming more conscious of the food they eat, leading to a higher demand for healthy, chemical-free food. Because of this, researchers are seeking better, safer, and equally effective alternatives to prevent postharvest losses. Among these postharvest technology alternatives is the application of edible coatings. Edible coatings are environmentally sustainable strategies for food preservation [3], as they can replace synthetic chemicals and packaging materials. These are thin layers of natural biopolymers applied to the surfaces of fruits and vegetables that act as semipermeable barriers, reducing transpiration, moisture loss, and pathogen contamination while maintaining the produce's nutritional and visual quality. Edible coatings are generally 0.3 mm thick and are made from layer materials used for enrobing food to fortify or replace natural layers consumed with the food [4]. The application of edible coatings to vegetables appears to be a promising approach for minimizing postharvest losses due to deterioration and disease. It can be done by brushing, spraying, wrapping, and dipping.

Chitosan, a biodegradable polysaccharide biopolymer extracted from chitin found in crustacean shells, is widely recognized for its excellent film-forming ability, antimicrobial activity, and biodegradability, and has shown promising results in extending the shelf life and quality of produce [5, 6]. Aloe vera plant produces a mucilaginous gel obtained through extraction from the jelly-like substance of the parenchyma tissue of its leaves. It is used as a novel edible coating due to its moisturizing effect, exceptional barrier properties, and antifungal and antibacterial properties, which are biologically safe, helping extend the shelf life of fruits and vegetables. The commercial application of Aloe vera gel is considered an alternative to postharvest chemical treatments, as it is safer to consume at the recommended concentration. Moringa oleifera, as a medicinal tree, has numerous economic applications and uses in human consumption [7]. Its extracted leaves can be used in the food industry as a potential post-harvest treatment agent. The extract from leaves contains natural antioxidants, including ascorbic acid, phenolic compounds, and carotenoids, which contribute to reducing microbial activity in fruits and vegetables.

Chitosan alone as a coating material has remarkable properties; however, additional properties are essential when combined with bioactive plant components to develop multifunctional coatings with both barrier and antimicrobial properties, to achieve food security. Furthermore, less information is available on the combined application of a chitosan edible coating enriched with Aloe vera gel and moringa leaf extracts. Therefore, this study evaluated the synergistic effect of chitosan enriched with Aloe vera gel and moringa leaf extracts on the physico-chemical postharvest properties of bell pepper under ambient room conditions.

2. Materials and Methods

2.1 Location

The study was conducted at the Cebu Technological University-Argao Campus-Biodiversity, Environment and Natural Resources Research Center (CTU-BENRC), Argao, Cebu, under tropical ambient conditions.

2.2 Fruit Sample Preparation

Newly harvested, commercially mature, green "Emperor F1" bell peppers were purchased from the local farmer in Nug-as, Alcoy, Cebu, properly packed in suitable containers, and immediately transported to the CTU-Argao BENRC Laboratory. Only healthy, fresh, uniform-sized, and disease-free fruits were selected for application of various postharvest treatments. The collected fruit samples were washed with tap water, then decontaminated with 30% commercial bleach, and rinsed 3 times with sterile water.

2.3 Study 1: Effects of Different Chitosan Edible Coating Concentration on Physico-chemical Properties of Bell Pepper (*Capsicum annuum* L.) Fruits

The study was conducted in a series of experiments to determine optimal chitosan edible coating formulations for preserving quality and extending the shelf life of bell peppers. In these experiments, the

effects of different concentrations of edible coating formulations on bell pepper fruit were evaluated using general quality parameters and chemical properties. Then, the edible coating, which has the potential to preserve quality and extend the shelf life of these fruits, was selected and incorporated with Aloe vera gel and Moringa Leaf Extracts, and tested for general quality parameters and physico-chemical properties in Study 2.

2.4. Preparation of Chitosan Edible Coating Solution

A study by [8] served as a guide for preparing the coating. To prepare 100 ml of chitosan solutions at concentrations 1, 2, 3, and 4 g/L, 1, 2, 3, and 4 g of chitosan powder were weighed using a sensitive balance. Each amount of chitosan was dissolved in 75 ml of distilled water containing 1 ml of glacial acetic acid, then placed on a magnetic stirrer for 60 minutes to ensure complete dissolution. The final pH of the solution was adjusted to 5.6 with 0.1 M NaOH, and the volume was made up to 100 mL with distilled water.

2.5 Method of Coating Application

Food-grade chitosan was used to coat bell pepper fruits. A total of 150 freshly harvested, healthy, uncontaminated, and uniform-sized bell pepper fruits were selected for Study 1. The bell pepper fruits were dipped in the respective coating formulations for 7 minutes and left to dry at room temperature. After drying, the treated bell peppers were placed in a plastic mesh tray and stored under ambient room conditions.



Figure 1. Preparation of Chitosan Coating



Figure 2. Application of Chitosan Coatings

2.6 Experimental Design and Treatments

The study was laid out in a Completely Randomized Design (CRD) with five treatments and three replications, with ten samples per treatment per replicate.

The treatments were as follows:

C0- No coating

C1- 1g chitosan powder was dissolved in 100 ml of distilled water (1% w/v)

C2- 2g chitosan powder was dissolved in 100 ml of distilled water (2% w/v)

C3- 3g chitosan powder was dissolved in 100 ml of distilled water (3% w/v)

C4- 4g chitosan powder was dissolved in 100 ml of distilled water (4% w/v)

2.7 Study 2: Comparative Effects of Chitosan and Plant Extract- Based Edible Coating on Physicochemical Properties of Bell Pepper (*Capsicum annuum* L.) Fruits

For this study, the optimum chitosan concentration from study 1 was combined with different ratios of Aloe vera gel and moringa leaf extracts. These coatings were prepared to enrich the coating.

2.8 Aloe vera Gel Preparations

Preparations of Aloe vera extracts were based on the method of [9] with slight modifications, where Aloe vera leaves were obtained and prepared fresh from the field. All edges of the Aloe vera leaves were cut using a knife and soaked in water for 30 minutes before scraping the gel. The colorless, gel-like material obtained is called hydro parenchyma. Using a spoon, it was scraped into a blender and blended to a slimy consistency. This solution was then filtered through a strainer with 8 mm holes to remove water and the fibrous fraction. A pure, 100% aloe vera solution was stored at 5°C in a refrigerator until use to prevent oxidation of the phenolic compounds.

2.9 Moringa Leaf Extracts

The moringa leaf extraction process was carried out according to the method described by [10]. Young leaves below the apical portion of the moringa tree were collected. Moringa leaves were separated from stalks and sorted to remove the yellow and brown leaves. The leaves were washed with distilled water to remove dirt, and afterward spread out on clean tissue paper. The extract was obtained by grinding the young leaves with 1 ml of distilled water per 10g of fresh moringa leaves, as described by [10], using a conventional juicer blender. The solid materials were separated from the juice using a strainer with 8 mm holes. The extract was collected in a separate container and prepared following the recommended dilutions for moringa leaf extracts [10, 11].

2.10 Experimental Design and Treatment

The study used the 2% chitosan concentration, as it was the optimum concentration determined in Study 1. Additionally, the study was laid out in a single-factor experiment in a Completely Randomized Design (CRD) with five treatments and three replications with 10 samples per replicate. Each treatment used the optimal chitosan concentration solution, determined in Study 1, as a consistent base to assess the synergistic effects of Aloe vera and Moringa leaf extracts at varying percentages. T0 served as the control, with the optimum chitosan concentration (2%) used. T1 was prepared by homogenizing 50 mL of the optimal chitosan concentration with 50 mL of Aloe vera gel, as recommended by [12]. T2 was prepared by homogenizing 33 mL of the optimum chitosan concentration with 67 mL of Aloe vera gel, aiming to offer a low-cost technology that farmers can adopt by increasing the volume of Aloe vera extract. For T3, the solution was prepared by homogenizing 50 mL of the optimal chitosan concentration with 50 mL of 20% Moringa leaf extract, as recommended by [10, 11]. T4 was prepared by homogenizing 33 mL of the optimum chitosan concentration with 67 mL of Moringa leaf extract, also aiming to provide a low-cost technology by increasing the proportion of Moringa leaf extract. Homogenization time was standardized at 3 minutes for all preparations, as described by [12].

2.11 Data Collection

Cumulative Weight Loss (%). The initial weight of the fruits was measured before the treatments were applied. The fruits' weights were evaluated every other day after treatments were applied to determine weight loss. The following formula calculates weight loss.

$$\text{Weight loss (\%)} = (W_i - W_t) / W_i \times 100$$

where:

W_i - initial weight

W_t - Weight after every other day observation

Fruit Shriveling - This was determined through the use of the shriveling index (SI) [13].

Firmness index- The degree of fruit firmness was evaluated every other day using the palpation-based firmness index method described by [13]. This method involves the manual palpation of sample fruits from each treatment per replicate to determine relative firmness levels and ensure consistency in assessment across the sampling period. To minimize experimental error and ensure reliable data, strict care was taken with the fruits during each evaluation.

Visual Quality Rating and Shelf Life - The physical appearance of bell pepper fruit was assessed every other day using the 9-point hedonic scale of [13].

Decay Incidence/Spoilage. Decay incidence was calculated as the number of decayed/diseased fruits divided by the total number of fruits. The fruits were visually inspected for rotting and microbial infection. Percent decay incidence was calculated using the formula.

$$\text{Decay Incidence (\%)} = \frac{\text{number of decayed fruits}}{\text{Total number of fruits}} \times 100$$

pH level. A gram of bell pepper fruit from each treatment was cut into small slices and pooled. Samples were homogenized in a blender, and portions of the homogenate were taken for quality assessment. The pH value of the fruit was measured with a pH meter.

Total Soluble Solid (0Brix). A composite sample of 5 g of fruit flesh per treatment was prepared, blended, homogenized with 50 mL of distilled water, and filtered. The filtrate was analyzed for TSS. TSS in Brix% was measured using a hand-held refractometer calibrated with distilled water by placing 1-3 drops of juice on the instrument's prism and taking the reading.

Titrateable Acidity (%) – A five (5) mL aliquot of fruit juice extract was taken from blended and homogenized samples and diluted with 45 mL of distilled water. The aliquot was measured, placed in an Erlenmeyer flask, and treated with 2 drops of 1% phenolphthalein indicator. This was titrated with 0.1% NaOH until the faint pink color, and the volume of NaOH was recorded, and TA was calculated as follows [13]:

$$\% \text{ TA of predominant acid}$$

Where:

V- Volume of NaOH added, ml

N- Concentration of NaOH, normality (N)

M- Milliequivalent weight of predominant acid, g/meq (citric acid- 0.064)

W- Weight equivalent of aliquot, g

2.12 Relative Humidity and Temperature

The ambient storage temperature and relative humidity (RH) were monitored twice daily, in the morning (AM; 07:00–08:00 h) and the afternoon (PM; 13:00–14:00 h) throughout the 16-day storage period, for both Study 1 and Study 2. Recordings were made using a calibrated digital thermo-hygrometer placed inside the storage room of the CTU-Argao Campus BENRC Laboratory, Argao, Cebu, Philippines, where all treatment groups were stored under identical, uncontrolled tropical ambient conditions with no refrigeration or modified atmosphere.

2.13 Statistical Analysis

Statistical analysis was performed using the Statistical Tool for Agricultural Research (STAR) software. One-way ANOVA test at a significance level of 5%, and Least Significant Difference (LSD) Test for comparisons among treatments were performed.

3. Results and Discussion

3.1 Weight Loss

Weight loss is one of the most critical postharvest factors influencing the marketability of fresh produce. The evaluation of the percentage weight loss in bell peppers over a period of sixteen (16) days under five (5) treatments with different concentrations of chitosan (T0–T4) is shown in Table 1. The weight loss of bell pepper fruits increased progressively with storage time, and significant differences among treatments were observed, particularly during the early to mid-storage period. Table 1 shows that at 2 days of storage, the control (T0) already lost 7.45% of its weight, while the 2% chitosan coating (T2) showed a much lower weight loss of only 4.43%. The analysis confirmed that these differences were statistically significant, indicating that even at the start of storage, coating concentration had a measurable impact on fruit dehydration. Interestingly, the higher concentrations (T3 – 8.06% and T4 – 7.58%) recorded values comparable to or even greater than the control, suggesting that overly thick coatings in T3 and T4 may have failed to regulate water vapor loss effectively. This aligns with reports by [14], who emphasized that excessively thick coatings can hinder normal gas exchange, which may explain why T3 and T4 did not outperform the control in this study. By day 6, treatment differences became more pronounced. Fruits under T2 maintained the lowest weight loss (14.54%), significantly lower than the control (21.73%), while T1 (18.57%) provided moderate protection. This trend continued through days 8 and 10, where T2 fruits consistently had 6–8% less weight loss than the control and other treatments. By day 12, the advantage of T2 remained evident (31.39%) compared to T0 (40.56%), confirming that chitosan coatings remained highly effective through this stage. However, by day 14 and day 16, treatment differences were no longer significant, with all fruits exceeded 50% weight loss. It is important to acknowledge that the commercially acceptable threshold for bell pepper weight loss is typically 5–8%; fruit exceeding this threshold would be unmarketable under commercial standards. In this study, shelf life is therefore defined operationally based on Visual Quality Rating (VQR ≥ 5.0 on the hedonic scale) rather than weight loss alone, as VQR integrates multiple visible quality attributes. At this stage, natural senescence and tissue breakdown dominated storage behavior, overriding the protective effects of the coatings. These observations highlight that while chitosan delays water loss, it cannot indefinitely suppress the natural progression of postharvest deterioration.

Table 1. Percent (%) weight loss of the bell pepper fruit (*Capsicum annuum* L.) as influenced by the different concentrations of chitosan edible coating.

Treatments	Means (Per day)							
	2	4	6	8	10	12	14	16
T0- Uncoated	7.45 ^a	14.32 ^{ab}	21.73 ^a	28.33 ^a	34.47 ^a	40.56 ^a	52.98	60.05
T1- 1% Chitosan	6.20 ^{ab}	12.75 ^b	18.57 ^b	25.68 ^a	32.03 ^a	37.94 ^b	53.82	59.88
T2- 2% Chitosan	4.43 ^b	9.26 ^c	14.54 ^c	20.70 ^b	26.28 ^b	31.39 ^c	53.57	59.12
T3- 3% Chitosan	8.06 ^a	14.43 ^{ab}	21.46 ^a	27.99 ^a	33.73 ^a	40.33 ^{ab}	52.74	59.25
T4- 4% Chitosan	7.58 ^a	15.19 ^a	21.67 ^a	28.38 ^a	34.53 ^a	42.10 ^a	54.76	62.16
F Value	5.57	11.38	15.93	12.80	13.96	27.08	0.75	1.87
Pr (> F)	0.0127	0.0010	0.0002	0.0006	0.0004	0.0000	0.5827	0.1922
CV (%)	15.91	9.22	6.91	6.05	4.98	3.66	2.97	2.58

Means within the same column in a block, followed by a common letter and/or without letter designations, are not significantly different from each other at 5% level of significance.



Figure 3. Weighing of Bell Pepper Fruit

3.2 Fruit Shriveling

Table 2 presents the shriveling scores of bell peppers treated with different concentrations of chitosan over a 16-day storage period. Shriveling, often associated with moisture loss and loss of firmness, directly impacts visual quality and consumer acceptance. The application of chitosan coatings significantly influenced the shriveling behavior of bell peppers during storage. Statistical analysis revealed significant differences in shriveling at 2, 10, and 16 days, indicating that treatment formulations influenced bell pepper moisture retention during storage and suggesting that chitosan concentration plays a crucial role in maintaining fruit quality over time. Data show that the control (T0) consistently had the highest shriveling scores throughout the storage period, reaching 4.93 by day 16, indicating rapid deterioration in the absence of a protective coating. In contrast, coated fruits exhibited delayed shriveling, with T2 (2% chitosan) consistently performing best, achieving the lowest shriveling score of 3.67. This demonstrates that chitosan effectively served as a semipermeable film, reducing water vapor loss and maintaining firmness. [15] Similarly, it was reported that chitosan coatings delay shriveling in bell peppers by preserving water content and reducing desiccation symptoms. By day 10, significant differences among treatments became more apparent. The control (T0) registered a shriveling score of 2.90, which was markedly higher than T1 (2.50), T2 (2.67), and T3 (2.53). Among all treatments, T2 maintained the numerically lowest mean shriveling score (2.21) across the entire storage period, outperforming T0 (2.48), T1 (2.33), T3 (2.38), and T4 (2.43) in overall moisture retention. Interestingly, while chitosan was effective overall, higher concentrations (T3 = 3% and T4 = 4%) did not always outperform 2% chitosan. In fact, excessively thick coatings may hinder gas exchange, reducing oxygen availability and triggering anaerobic respiration, thereby accelerating quality decline [16]. Also noted that moderate concentrations (~2%) yield optimal effects due to proper film formation and permeability, while very low or very high concentrations compromise effectiveness. This pattern aligns with previous findings by [17, 18] and [19], who emphasized the concentration-dependent response of chitosan, where excessively thick coatings may disrupt physiological balance, while thin coatings may fail to provide adequate protection. The average shriveling scores over the entire storage duration further support this trend. T0 had the highest mean shriveling (2.48), while T2 maintained the lowest average (2.21), followed closely by T1 (2.33). Treatments T3 (2.38) and T4 (2.43) did not show improvement beyond the effectiveness of 2% chitosan. This suggests that selecting an optimal coating level to balance moisture retention and gas exchange, and a moderate chitosan concentration (2%) provides the best protection against shriveling, whereas higher concentrations may not yield additional benefits.

Table 2. Shriveling of the bell pepper fruit (*Capsicum annuum* L.) as influenced by the different concentrations of chitosan edible coating.

Treatments	Means (Per day)							
	2	4	6	8	10	12	14	16
T0- Uncoated	1.00 ^b	1.17	1.47	2.00	2.90 ^a	3.03	3.33	4.93 ^a
T1- 1% Chitosan	1.03 ^b	1.20	1.50	2.07	2.50 ^c	2.80	3.20	4.30 ^b
T2- 2% Chitosan	1.00 ^b	1.10	1.43	2.03	2.67 ^{abc}	2.80	3.00	3.67 ^c
T3- 3% Chitosan	1.10 ^{ab}	1.23	1.67	1.97	2.53 ^{bc}	2.90	3.17	4.47 ^{ab}
T4- 4% Chitosan	1.17 ^a	1.47	1.63	2.03	2.80 ^{ab}	2.87	3.00	4.47 ^{ab}
F Value	4.70	2.65	0.88	0.93	3.76	1.01	2.07	7.23
Pr (> F)	0.0215	0.0962	0.5086	0.4853	0.0407	0.4460	0.1602	0.0053
CV (%)	5.45	12.03	12.43	3.38	5.70	5.74	5.45	6.74

*Means within the same column in a block, followed by a common letter and/or without letter designations, are not significantly different from each other at 5% level of significance.

**Figure 4.** First day of Bell Pepper fruit storage (Study 1)**Figure 5.** Final day of Bell Pepper fruit storage (Study 1)

3.3 Firmness

Fruit firmness is one of the most important quality attributes influencing consumer preference and marketability. In this study, significant differences in firmness were observed at multiple storage intervals (days 2, 4, 6, 10, and 16). At day 6, fruits treated with 3% and 4% chitosan (T3 and T4, respectively) maintained significantly higher firmness (2.03 and 2.00, respectively) than the uncoated control (1.87). However, by day 10, fruits coated with 4% chitosan (T4) exhibited lower firmness (2.73) than those in other treatments, suggesting that excessively thick coatings may interfere with normal gas exchange, thereby accelerating softening. By day 16, the highest firmness was recorded in T0 (5.00), while coated fruits exhibited slightly lower values, with T2 (4.10) being the lowest. This may be attributed to natural textural changes during ripening, where chitosan coatings delayed but could not fully prevent the eventual breakdown of cell wall polysaccharides. It should be noted that in this palpation-based firmness index, lower scores reflect better-quality fruit (less dehydration), and higher scores indicate desiccation and tissue collapse. The overall average firmness index of coated fruits (2.54–2.66) was numerically lower than that of the uncoated control (2.70),

suggesting that chitosan coatings reduced desiccation-driven hardening during the early stages of storage. The marginal numerical difference, however, should be interpreted with caution, given the subjective nature of the measurement method.

The overall average firmness was highest in coated treatments, with T2 (2% chitosan) showing the most stable firmness across storage days. This confirms that moderate chitosan concentrations act as effective semipermeable barriers, delaying cell wall degradation and maintaining tissue integrity [20, 21]. These findings also agree with [17], who reported that chitosan coatings maintained firmness in tomatoes by reducing respiration and slowing the enzymatic degradation of cell wall structures, and align with [21], who noted that chitosan delays the activity of softening enzymes, such as polygalacturonase, thereby preserving texture. Similarly, [22] found that sweet peppers treated with chitosan retained firmness longer than untreated controls, due to the semipermeable nature of the coating, which modifies the fruit's internal microenvironment.

Table 3. Firmness of bell pepper fruit (*Capsicum annuum* L.) as influenced by different concentrations of an edible chitosan coating.

Treatments	Means (Per day)							
	2	4	6	8	10	12	14	16
T0- Uncoated	1.20	1.50 ^b	1.87	2.00	3.00	3.00	4.00	5.00 ^a
T1- 1% Chitosan	1.33	1.50 ^b	2.10	2.10	3.00	3.07	4.03	4.17 ^{cd}
T2- 2% Chitosan	1.03	1.33 ^b	1.87	2.00	2.97	3.00	4.00	4.10 ^d
T3- 3% Chitosan	1.27	1.40 ^b	2.03	2.00	3.00	3.00	4.00	4.60 ^b
T4- 4% Chitosan	1.37	1.73 ^a	2.00	2.00	2.73	3.00	4.00	4.40 ^{bc}
F Value	1.60	6.09	1.62	1.00	0.94	1.00	1.00	19.24
Pr (> F)	0.2483	0.0095	0.2448	0.4516	0.4804	0.4516	0.4516	0.0001
CV (%)	14.58	7.13	7.17	3.83	7.08	1.71	0.6444	3.23

Means within the same column in a block, followed by a common letter and/or without letter designations, are not significantly different from each other at 5% level of significance.

3.4 Visual Quality Rating and Shelf Life

Table 4 presents the Visual Quality Rating (VQR) of bell peppers treated with various chitosan-based coatings over a 16-day storage period. VQR is a direct indicator of marketability and consumer acceptability, where higher scores reflect better visual appearance and delayed senescence. Statistical analysis revealed significant differences in VQR among treatments at several time points, particularly at 6, 8, 12, 14, and 16 days. These results suggest that the applied coatings had a marked influence on maintaining visual quality, especially during the mid- to late-storage period. The application of chitosan coatings significantly influenced the visual quality rating (VQR) and shelf life of bell peppers during storage. During the initial storage period (2–4 days), no significant differences were observed among treatments (T0–T4), and all fruits maintained high VQR values (>8.5). This indicates that during the early stage, both coated and uncoated bell peppers retained acceptable marketable quality, suggesting that chitosan's protective effect becomes more evident as storage duration increases. Similar findings were reported by [18], who emphasized that coatings have a greater impact during prolonged storage. From day 6 onward, significant differences emerged among treatments. T2 (2% chitosan) consistently exhibited the highest VQR among the treatments, including the control and other coating concentrations. At 6 and 8 days, bell peppers treated with 2% chitosan maintained superior visual appeal, showing less shriveling and discoloration. This result agrees with [23], who noted that moderate chitosan concentrations form a semipermeable film that reduces respiration rate and moisture loss, thereby delaying senescence. By the later storage period (12–16 days), the effectiveness of chitosan became more apparent. The uncoated fruits (T0) deteriorated rapidly, with VQR values dropping below the marketable quality threshold (<4.0), whereas all coated treatments (T1–T4) maintained significantly higher ratings. Among them, T2 (2% chitosan) stood out with the highest VQR, maintaining consumer-acceptable quality for up to 2 weeks of storage. Treatments T1 (1%) and T3 (3%) also maintained acceptable quality but were less effective than T2, whereas T4 (4%) offered no substantial improvement and, in some cases, performed slightly worse.

This trend supports the observation of [24], who reported that excessive coating thickness may impede gas exchange, potentially causing anaerobic conditions and hastening deterioration.

3.5 Decay Incidence

Decay incidence is a key indicator of microbial spoilage and overall postharvest disease resistance in fresh produce. As shown in Table 5, the decay incidence of bell peppers varied significantly among treatments ($p < 0.001$), highlighting the influence of coating composition on microbial protection. The untreated control (T0) exhibited the highest decay incidence at 26.67%, with an average of 2.67 out of 10 fruits showing visible signs of decay by the end of the storage period. In contrast, all chitosan-based coatings were effective in reducing decay to varying degrees. The most notable result was observed in treatment T2 (2% Chitosan), which completely inhibited decay, recording a 0% incidence. This suggests a strong antimicrobial effect of 2% chitosan. Higher concentrations (T3 and T4) still reduced decay compared to the control but were less effective than T2, possibly because coating thickness affected gas balance. The antimicrobial properties of chitosan, attributed to its polycationic nature, which disrupts microbial cell membranes, explain this reduction [16, 21].

Table 4. VQR and shelf life of the bell pepper fruit (*Capsicum annuum* L.) as influenced by the different concentrations of chitosan edible coating.

Treatments	Total No. of Fruits	Decayed Fruits	Decay Incidence
T0- Uncoated	30	8	26.67 ^a
T1- 1% Chitosan	30	4	13.33 ^{ab}
T2- 2% Chitosan	30	0	0.00 ^b
T3- 3% Chitosan	30	7	23.33 ^a
T4- 4% Chitosan	30	6	20.00 ^a
F Value			5.56
Pr (> F)			0.0128
CV (%)			46.48

Means within the same column in a block followed by a common letter and/or without letter designations are not significantly different from each other at 5% level of significance.

Table 5. Decay incidence of bell pepper fruit (*Capsicum annuum* L.) as influenced by different concentrations of edible chitosan coating.

Treatments	Means (Per day)							
	2	4	6	8	10	12	14	16
T0- Uncoated	8.73	8.67	7.40 ^b	7.00 ^b	6.60	5.90 ^c	5.10 ^c	3.47 ^b
T1- 1% Chitosan	8.97	8.70	7.80 ^b	7.40 ^b	7.10	6.67 ^b	6.30 ^b	5.33 ^a
T2- 2% Chitosan	9.00	9.00	8.60 ^a	8.13 ^a	7.53	7.37 ^a	6.97 ^a	6.33 ^a
T3- 3% Chitosan	8.93	8.80	7.77 ^b	7.33 ^b	7.13	6.63 ^b	6.23 ^b	5.37 ^a
T4- 4% Chitosan	8.90	8.63	7.53 ^b	7.27 ^b	7.13	6.63 ^b	6.13 ^b	5.27 ^a
F Value	0.62	0.81	5.47	4.71	3.00	5.58	42.17	6.63
Pr (> F)	0.6574	0.5480	0.0135	0.0213	0.0723	0.0126	0.0000	0.0071
CV (%)	2.56	3.26	4.42	4.55	4.67	5.73	2.91	13.57

Means within the same column in a block, followed by a common letter and/or without letter designations, are not significantly different from each other at 5% level of significance.



Figure 6. Fungus-infected bell pepper (*Capsicum annuum* L.) fruits

3.6 pH

Table 6 shows that the pH values of bell peppers increased gradually throughout storage across all treatments, indicating the natural ripening process marked by the degradation of organic acids. Statistical analysis revealed significant differences among treatments at all storage intervals. On the final day, the control (T0) recorded the highest pH (5.20a), while the 2% chitosan treatment (T2) maintained the lowest (5.04c). This demonstrates that chitosan coatings, especially at 2%, effectively slowed down the rise in pH by reducing the consumption of organic acids. [23] and [19] explained that chitosan acts as a semipermeable barrier, lowering respiration and ethylene production, and significantly slowing pH increases by acting as a gas barrier, thus conserving acidity and delaying senescence. Similar findings were reported by [19] for coated strawberries and by [17, 18] for bell peppers, where coatings helped maintain lower pH levels than in untreated fruits. Additionally, treatments T3 (3% chitosan) and T4 (4% chitosan) showed intermediate values (5.17ab). These results suggest that chitosan coatings delayed the rise in pH by conserving organic acids, with T2 showing the most pronounced effect. The effect of chitosan on pH is attributed to its ability to form a semipermeable film that modifies the fruit's internal atmosphere by limiting oxygen diffusion and slowing respiration [21]. This reduced metabolic rate delays the consumption of organic acids such as citric, malic, and ascorbic acid, which are major contributors to the fruit's acidity.

Table 6. Initial, 5th day, 10th day, and final pH of bell pepper fruit (*Capsicum annuum* L.) as influenced by the different concentrations of chitosan edible coating.

Treatments	pH at			
	Initial	5 th day	10 th day	Final
T0- Uncoated	4.91 ^c	5.04 ^a	5.13 ^a	5.20 ^a
T1- 1% Chitosan	4.95 ^{ab}	5.01 ^a	5.06 ^b	5.11 ^b
T2- 2% Chitosan	4.91 ^c	4.94 ^b	4.96 ^c	5.04 ^c
T3- 3% Chitosan	4.98 ^a	5.03 ^a	5.12 ^a	5.17 ^{ab}
T4- 4% Chitosan	4.95 ^b	5.01 ^a	5.08 ^{ab}	5.17 ^{ab}
F Value	7.55	6.67	17.40	9.82
Pr (> F)	0.0045	0.0070	0.0002	0.0017
CV (%)	0.3696	0.5235	0.5578	0.6688

Means within the same column in a block, followed by a common letter and/or without letter designations, are not significantly different from each other at 5% level of significance.

3.7 Total Soluble Solids

TSS, expressed in °Brix, reflects the sugar content of the fruit and is a key determinant of sweetness and overall taste quality. Table 7 showed variations across treatments from the first day until the last day of storage. During storage, the TSS of bell peppers generally increased until day 10, then declined at the final evaluation. This trend corresponds to the conversion of starches and organic acids into sugars during ripening, followed by sugar utilization in respiration at later stages [25]. The different chitosan coating concentrations influenced the total soluble solids (TSS) of bell pepper fruits during storage. Initial TSS values were similar across treatments (5.10–5.30 °B), with no significant differences. By the 5th day, TSS values started to vary slightly, ranging from 5.47 °B (T2) to 6.13 °B (T0), although differences remained statistically non-significant. Significant differences became apparent on the 10th day. The control (T0) registered the highest TSS (6.93), followed by T4 (6.40) and T3 (6.27). In contrast, T2 (5.87) maintained the lowest TSS value, while T1 (6.10) was intermediate. This trend indicates that uncoated fruits ripened more rapidly, leading to higher sugar accumulation, whereas chitosan coatings, especially at 2%, slowed the conversion of starch and organic acids into soluble sugars. By the final day of storage, highly significant differences were observed, with the control (T0) still exhibiting the highest TSS (5.93), while T2 decreased sharply to 4.07. Treatments T3 (5.50) and T4 (5.60) were statistically comparable but lower than the control. This pattern highlights that chitosan-coated fruits not only accumulated sugars more slowly but also retained them for a longer period by reducing respiration-driven sugar depletion, whereas the uncoated control experienced rapid ripening followed by sugar decline. The TSS trend is consistent with the pH and TA results. The control (T0), which showed the highest TSS values, also recorded the highest pH (5.20) and lowest TA (0.18) at the end of storage, reflecting advanced ripening and metabolic acid depletion. Conversely, T2 fruits exhibited the lowest TSS (4.07), lowest pH (5.04), and highest TA (0.26), indicating delayed ripening and preservation of the acid–sugar balance.

These findings confirm the interconnected role of sugar accumulation and acid degradation during fruit maturation. Similar results were reported by [26] for cold-stored fruit and by [27] for litchis, where chitosan coatings reduced sugar accumulation by slowing respiration. [28] Further explained that coatings limit oxygen availability, thereby decreasing enzymatic activities responsible for sugar metabolism. In bell peppers, [17]. Also observed that chitosan significantly reduced the rise in TSS, supporting the present findings.

Table 7. Initial, 5th day, 10th day, and final TSS of bell pepper fruit (*Capsicum annuum* L.) as influenced by different concentrations of edible chitosan coating.

Treatments	TSS (°Brix) at			
	Initial	5 th day	10 th day	Final
T0- Uncoated	5.30	6.13	6.93 ^a	5.93 ^a
T1- 1% Chitosan	5.30	5.63	6.10 ^{bc}	5.30 ^b
T2- 2% Chitosan	5.30	5.47	5.87 ^c	4.07 ^c
T3- 3% Chitosan	5.10	5.70	6.27 ^{bc}	5.50 ^{ab}
T4- 4% Chitosan	5.20	5.80	6.40 ^b	5.60 ^{ab}
F Value	0.71	2.63	7.73	24.28
Pr (> F)	0.6059	0.0977	0.0042	0.0000
CV (%)	3.52	4.60	3.94	4.77

Means within the same column in a block followed by a common letter and/or without letter designations are not significantly different from each other at 5% level of significant.

3.8 Titratable Acidity

TA is another critical indicator of fruit quality, reflecting the concentration of organic acids, such as citric, malic, and ascorbic acids. Acidity provides peppers with their characteristic tangy flavor and contributes to their microbial stability. Table 8 shows that the titratable acidity (TA) of bell pepper fruits declined progressively during storage across all treatments, reflecting the natural utilization of organic acids as substrates in respiration and metabolic reactions. Statistical analysis revealed significant differences among treatments starting at the 5th day, with the differences becoming more pronounced at the 10th and final days. Initial TA values were comparable (0.38–0.41%) and did not differ significantly. By the 5th day, however,

statistical differences emerged; the highest TA was observed in T2 (0.36a), while the lowest was in T4 (0.30b) and T0 (0.31b). This early variation suggests that chitosan coatings, particularly at 2%, were effective in slowing down the metabolic depletion of organic acids. Moreover, differences became more pronounced at the 10th day, where the control (T0) showed a sharp decline to 0.23c, while T2 (0.31a) and T3 (0.30a) maintained significantly higher acidity. By the final day, TA values ranged from 0.18c (T0) to 0.26a (T2), with T3 (0.24ab) and T4 (0.23ab) maintaining intermediate levels. These results clearly indicate that 2% chitosan (T2) was most effective in preserving acidity, delaying senescence, and maintaining postharvest quality. Table 8 clearly shows that the TA trend is closely associated with the observed pH and TSS results. The control (T0), which exhibited the lowest TA (0.18c), also recorded the highest pH (5.20a) and TSS (5.93a) at the end of storage, reflecting advanced ripening characterized by acid depletion and sugar accumulation. Conversely, T2 maintained the highest TA (0.26a), the lowest pH (5.04c), and the lowest TSS (4.07c), suggesting delayed metabolic activity and preservation of the acid–sugar balance. This interdependence confirms that chitosan reduced the degradation of organic acids into sugars and lowered sugar consumption during respiration. Coatings such as chitosan act as semipermeable barriers that slow respiration and ethylene production, thereby conserving organic acids and delaying their conversion into sugars [19, 23]. This mechanism has also been reported in strawberries [28], cherries [29], and plums [30], where coated fruits exhibited higher TA and lower TSS compared to controls, and it was noted by [30] that coatings act as protective barriers that limit oxygen diffusion, slowing enzymatic activities involved in organic acid metabolism.

Table 8. Initial, 5th day, 10th day, and final Titratable Acidity (TA) of bell pepper fruit (*Capsicum annuum* L.) as influenced by the different concentrations of chitosan edible coating.

Treatments	TA (%) at			
	Initial	5 th day	10 th day	Final
T0- Uncoated	0.38	0.31 ^b	0.23 ^c	0.18 ^c
T1- 1% Chitosan	0.39	0.32 ^b	0.28 ^{ab}	0.21 ^{bc}
T2- 2% Chitosan	0.41	0.36 ^a	0.31 ^a	0.26 ^a
T3- 3% Chitosan	0.39	0.33 ^{ab}	0.30 ^a	0.24 ^{ab}
T4- 4% Chitosan	0.39	0.30 ^b	0.26 ^{bc}	0.23 ^{ab}
F Value	0.90	3.97	7.25	6.97
Pr (> F)	0.4994	0.0349	0.0042	0.0060
CV (%)	5.10	6.17	7.25	8.93

Means within the same column in a block followed by a common letter and/or without letter designations are not significantly different from each other at 5% level of significant.

3.9 Relative Humidity and Temperature

Ambient temperature and relative humidity (RH) were monitored twice daily throughout the 16-day storage period at the CTU-Argao BENRC Laboratory under uncontrolled tropical indoor conditions. Mean daily temperature ranged from 30.3°C (Day 0) to 33.0°C (Day 16), with an overall mean of 31.6°C, while mean daily RH ranged from 69.2% to 73.4% (overall mean: 71.5%). Morning readings were consistently cooler and more humid (AM temperature: 29.6–31.5°C; AM RH: 72.3–78.1%), while afternoon readings were warmer and drier (PM temperature: 31.0–34.4°C; PM RH: 65.8–69.9%). These conditions followed a clear progressive trend over the storage period mean daily temperature increased gradually from Day 0 through Day 16, while RH declined correspondingly, a pattern that closely mirrors the deterioration trajectories observed across all Study 1 quality parameters. From Day 8 onward, mean temperatures consistently exceeded 31.5°C, and by Day 16, afternoon readings reached 34.4°C, coinciding with the period of accelerated pH rise and TSS increase across all treatments, as organic acids were consumed more rapidly and starches were converted into soluble sugars. The concurrent decline in afternoon RH to as low as 65.8% reinforced transpirational water loss from fruit surfaces, directly consistent with the escalating weight loss and shriveling observed across all treatments, most notably from Day 10 onward, where quality deterioration accelerated sharply in the uncoated control.

The chitosan-coated treatments, particularly T2 (2% chitosan), demonstrated better buffering against worsening ambient conditions, maintaining lower pH and higher titratable acidity, and significantly reducing weight loss relative to the control throughout storage. These environmental data therefore provide the necessary quantitative context for interpreting treatment differences in Study 1, and results obtained at ~31.6°C and ~71.5% RH should be considered when making comparisons with studies conducted under refrigerated or temperate storage conditions.

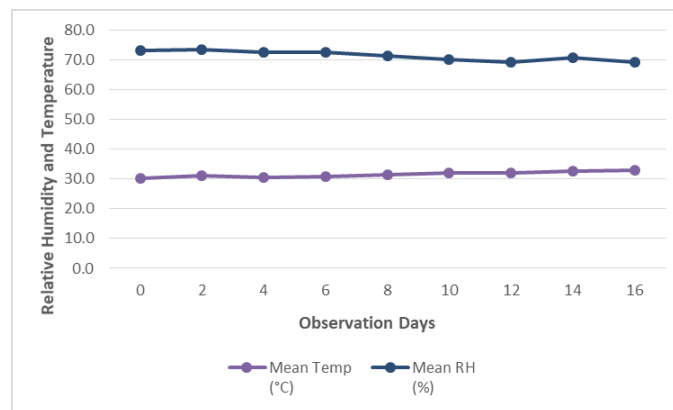


Figure 7. Relative humidity (%) and temperature (°C) during storage of bell pepper (*Capsicum annuum* L.) fruits

Table 9. Percent (%) weight loss of the bell pepper fruit (*Capsicum annuum* L.) as influenced by the different chitosan and plant extract-based edible coating.

Treatments	Means (Per day)							
	2	4	6	8	10	12	14	16
T0- 2% Chitosan	6.06 ^{bc}	14.08	23.10	28.60	38.30	44.69	52.84	62.02
T1- 50ml of 2% Chitosan + 50ml of 50% Aloe Vera	7.03 ^a	14.07	23.77	31.98	39.88	46.19	54.97	61.55
T2- 33ml of 2% Chitosan + 67ml of 50% Aloe Vera	5.90 ^c	13.69	21.56	30.84	38.12	44.59	52.67	60.88
T3- 50ml of 2% Chitosan + 50ml of 50% Moringa Leaf Extracts	7.32 ^a	15.61	23.41	31.64	39.69	46.81	55.42	63.38
T4- 33ml of 2% Chitosan + 67ml of 50% Moringa Leaf Extracts	6.88 ^{ab}	15.58	23.10	31.99	39.45	45.60	53.47	61.63
F Value	4.73	1.38	0.73	1.22	0.33	0.36	0.44	0.19
Pr (> F)	0.0211	0.3094	0.5918	0.3624	0.8499	0.8297	0.7807	0.9369
CV (%)	7.51	9.25	7.46	7.22	6.30	6.03	6.12	5.91

Means within the same column in a block followed by a common letter and/or without letter designations are not significantly different from each other at 5% level of significant.

3.10 Weight Loss

The weight loss of bell pepper fruits was monitored over a 16-day storage period to evaluate the effects of different chitosan-based treatments combined with Aloe vera and Moringa leaf extracts. The results are presented in Table 9. At 2 days, significant differences were observed among the treatments. The lowest weight loss was recorded in T2 (5.90%), which combined 33 mL of 2% chitosan with 67 mL of 50% Aloe vera gel. This suggests that the increased proportion of Aloe vera contributed positively to reducing moisture loss, likely due to its gel-like, hygroscopic nature and film-forming ability. In contrast, T3 (7.32%), which used chitosan and Moringa leaf extract in equal volumes, showed the highest weight loss at this time point, although it was not statistically different from T0, T1, and T4. From day 4 onward, no statistically significant differences were

observed among the treatments, although slight trends were noted. This aligns with the findings of [31], who reported that while chitosan reduces respiration and transpiration, additional plant extracts may not always significantly improve weight-loss control. Table 9 shows that T2 consistently exhibited slightly lower weight loss than other treatments, particularly at 6 and 8 days. However, by day 10 and beyond, the weight loss values across all treatments began to converge, with final readings at 16 days ranging from 60.88% (T2) to 63.38% (T3). Despite this convergence, T2 generally maintained the lowest weight loss throughout the storage period, indicating that a higher Aloe vera ratio may enhance the barrier properties of the chitosan coating. The slight reduction in weight loss observed in T2 (33ml of 2% chitosan + 67ml of 50% of aloe vera) suggests that Aloe vera gel may enhance moisture barrier properties due to its high polysaccharide and mucilaginous content, as previously observed in mango and tomato fruits coated with Aloe vera-based films [18]. The lack of significant differences at later stages suggests that the effectiveness of the chitosan-based coatings in reducing weight loss diminishes over extended storage periods, potentially due to film degradation or increased respiration rates in the fruit.

3.11 Fruit Shriveling

Shriveling is a key indicator of moisture loss and overall postharvest deterioration in fresh produce. Table 10 presents the shriveling scores of bell peppers treated with various chitosan-based coatings over a 16-day storage period. Shriveling was assessed using a subjective scale, with higher values indicating greater visible wrinkling and surface collapse. The progression of shriveling in bell pepper fruits increased across storage duration in all treatments, as shown in Table 10. At the early stages of storage (2 and 4 days), shriveling scores were low across all treatments, with no significant differences observed. This suggests that during the initial storage period, moisture loss was minimal and not visibly distinguishable among the treatments. However, significant differences emerged on the 6th day, with T2 (33ml of 2% chitosan + 67ml of 50% aloe vera) consistently exhibiting the lowest shriveling scores (1.07 at day 6 and 1.23 at day 8), compared to T0, T1, T3, and T4. On average, T2 recorded a 1.85 shriveling score, significantly lower than the other treatments, which ranged from 2.25 to 2.31. This suggests that the higher proportion of aloe vera enhanced chitosan's protective effect. Aloe vera gel is known for its hydrophilic polysaccharides and moisture-retaining capacity, which minimize transpirational water loss [32]. Similarly, [14] highlighted that aloe vera coatings reduce water vapor permeability and effectively delay dehydration in fresh produce, effectively delaying shriveling and dehydration in peppers by reducing transpiration losses [33]. Thus, T2 effectively reduced fruit shriveling by combining the film-forming property of chitosan with the water-retentive capability of aloe vera.

Table 10. Shriveling of the bell pepper fruit (*Capsicum annuum* L.) as influenced by the different chitosan and plant extract-based edible coating.

Treatments	Means (Per day)							
	2	4	6	8	10	12	14	16
T0- 2% Chitosan	1.13	1.17	1.40 ^a	1.93 ^a	2.27	2.77 ^a	3.30 ^a	4.30 ^a
T1- 50ml of 2% Chitosan + 50ml of 50% Aloe Vera	1.10	1.23	1.40 ^a	1.83 ^a	2.37	2.77 ^a	3.43 ^a	4.37 ^a
T2- 33ml of 2% Chitosan + 67ml of 50% Aloe Vera	1.00	1.03	1.07 ^b	1.23 ^b	1.87	2.17 ^b	2.80 ^b	3.67 ^b
T3- 50ml of 2% Chitosan + 50ml of 50% Moringa Leaf Extracts	1.10	1.20	1.57 ^a	1.73 ^a	2.40	2.77 ^a	3.40 ^a	4.03 ^{ab}
T4- 33ml of 2% Chitosan + 67ml of 50% Moringa Leaf Extracts	1.07	1.17	1.40 ^a	1.67 ^a	2.30	2.67 ^a	3.47 ^a	4.27 ^a
F Value	0.82	1.04	3.66	6.16	3.31	3.83	5.25	3.69
Pr (> F)	0.5403	0.4337	0.0438	0.0091	0.0568	0.0388	0.0153	0.0429
CV (%)	8.95	11.13	12.10	11.19	9.15	8.79	6.35	6.26

Means within the same column in a block followed by a common letter and/or without letter designations are not significantly different from each other at 5% level of significant.



Figure 8. First day of Bell Pepper fruit storage (Study 2)

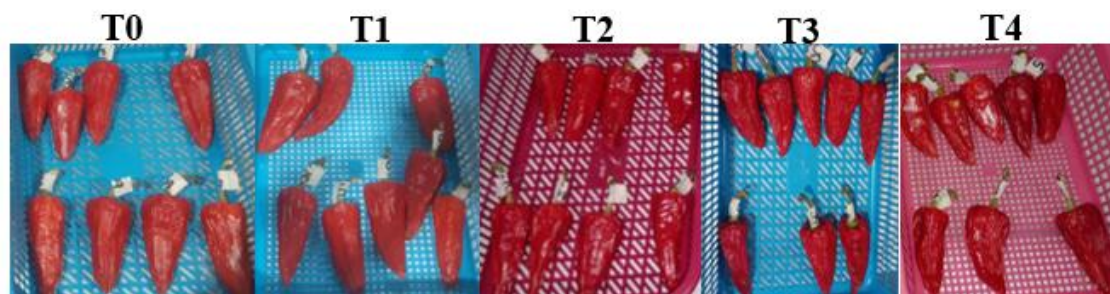


Figure 9. Final day of Bell Pepper fruit storage (Study 2)

3.12 Firmness

Firmness is a critical quality attribute in bell peppers. In this study, firmness was measured using a subjective palpation-based index, with higher scores indicating greater dehydration and tissue deterioration, not improved quality—consistent with the scale interpretation in Study 1. Loss of desirable texture during postharvest storage is primarily caused by cellular degradation, enzymatic activity, and moisture loss. The effects of various chitosan- and plant extract-based treatments on bell pepper firmness were assessed over a 16-day storage period, and the results are summarized in Table 11. Firmness index values increased progressively during storage for all treatments. Consistent with Study 1, higher index values in this palpation-based scale reflect greater desiccation and tissue deterioration, not improved quality. In bell pepper, higher firmness index readings are associated with moisture loss, tissue collapse, and increased shriveling, all of which negatively affect textural quality and consumer acceptability. Treatments yielding lower firmness index values thus indicate better preservation of quality. During the first 4 days of storage (2 and 4 days), there were no significant differences in firmness among treatments, indicating that all treatments were similarly effective at retaining initial fruit texture in the early postharvest stage. Statistical analysis confirmed significant differences among treatments on day 6. At this stage, T2 (1.10) recorded the lowest firmness, significantly lower than T3 (1.63) and T4 (1.50), which exhibited the greatest firmness loss. At day 16, the highest firmness values were observed in T4 (4.43) and T3 (4.40), followed by T1 (4.37) and T0 (4.20), while the lowest was recorded in T2 (3.87). On average, T2 (2.01) was significantly lower than T3 (2.40) and T4 (2.35), whereas T0 (2.23) and T1 (2.32) showed intermediate values.

Across the storage period, the average firmness ranged from 2.01 in T2 to 2.40 in T3, indicating that fruits in T2 consistently showed slower firmness increases, thus indicating better quality preservation. On the other hand, the relatively higher firmness values in T1, T3, T4, and even in the control T0 indicate that these fruits deteriorated faster, with more pronounced dehydration and tissue hardening. The effectiveness of T2 (33ml of 2% chitosan + 67ml of 50% aloe vera) in maintaining a lower firmness trend can be attributed to the hydrophilic polysaccharides and bioactive compounds in aloe vera, which delay water loss and maintain cell turgidity [32]. Conversely, treatments containing moringa leaf extracts (T3 and T4) recorded higher firmness values, suggesting that while moringa provides antioxidant protection [34, 35], it was less effective in controlling transpiration losses compared to aloe vera. Similarly, T1 (50 ml of 2% chitosan + 50ml of 50% aloe vera) maintained intermediate firmness values but still showed faster hardening than T2, likely due to the lower aloe vera concentration. The control (T0, 2% chitosan alone) exhibited firmness values similar to those

of T1, confirming the protective effect of chitosan, although aloe vera supplementation provided a greater advantage. These findings are consistent with [33], who reported that aloe vera-based coatings slowed down textural deterioration by preventing excessive water loss in coated fruits. Therefore, while all treatments delayed firmness increase, T2 formulation (33ml of 2% chitosan + 67ml of 50% aloe vera) emerged as the most effective in preserving desirable texture by maintaining the lowest firmness values throughout storage.

3.13 Visual Quality Rating and Shelf Life

The Visual Quality Rating (VQR), a subjective measure based on visual attributes such as color, freshness, shriveling, and decay, was used to assess the shelf life of bell pepper fruits over 16 days of storage (Table 12). Visual quality rating is a key parameter that reflects consumer acceptability of fresh produce during storage. Table 10 shows that the VQR remained relatively high across all treatments during the first 4 days, with no significant differences observed. However, by the 6th day, a trend emerged in which T2 (33ml of 2% chitosan + 67ml of 50% aloe vera) recorded a higher VQR (8.87) than T3 (7.93) and T4 (8.27), although the differences were not yet statistically significant. Significant variation emerged on the 8th day, with T2 maintaining the highest rating (8.67), while T3 (7.87) and T4 (8.07) had noticeably lower scores. This pattern persisted on days 10, 12, and 14, with T2 consistently recording significantly higher VQR scores than T3 and T4. By day 16, T2 still had the highest VQR (5.27), which was significantly greater than the other treatments, whose scores ranged from 4.07 to 4.53. Biologically, the superior VQR of T2 reflects its effectiveness in delaying external symptoms of deterioration such as shriveling, discoloration, and surface pitting. Aloe vera's natural polysaccharides form a thin, semipermeable film that reduces moisture loss and modifies internal gas

exchange, thereby slowing respiration and senescence [32, 33]. Chitosan also contributes by lowering ethylene production and providing antimicrobial protection [21], but its effect was clearly enhanced when combined with a higher proportion of aloe vera. By contrast, T3 and T4 (chitosan + moringa extracts) exhibited lower VQR values as storage progressed, indicating earlier deterioration. Although moringa leaf extracts contain antioxidants that may slow oxidative damage [34], they were less effective in preserving external appearance compared to aloe vera, possibly due to weaker film-forming properties. Similarly, T0 (2% chitosan alone) and T1 (50ml of 2% chitosan + 50ml of 50% of aloe vera) performed moderately well but did not maintain marketable quality as long as T2, suggesting that the higher aloe vera concentration was critical in extending shelf life.

Table 11. Firmness of the bell pepper fruit (*Capsicum annuum* L.) as influenced by the different chitosan and plant extract-based edible coatings.

Treatments	Means (Per day)							
	2	4	6	8	10	12	14	16
T0- 2% Chitosan	1.13	1.20	1.33 ^b	1.87	2.27	2.60	3.20 ^{ab}	4.20 ^{ab}
T1- 50ml of 2% Chitosan + 50ml of 50% Aloe Vera	1.10	1.23	1.43 ^b	1.87	2.30	2.90	3.33 ^{ab}	4.37 ^a
T2- 33ml of 2% Chitosan + 67ml of 50% Aloe Vera	1.00	1.03	1.10 ^c	1.50	2.07	2.50	3.03 ^b	3.87 ^b
T3- 50ml of 2% Chitosan + 50ml of 50% Moringa Leaf Extracts	1.10	1.20	1.63 ^a	2.03	2.43	2.90	3.47 ^a	4.40 ^a
T4- 33ml of 2% Chitosan + 67ml of 50% Moringa Leaf Extracts	1.07	1.10	1.50 ^{ab}	1.90	2.47	2.83	3.50 ^a	4.43 ^a
F Value	0.82	1.58	10.00	2.69	2.64	1.41	4.01	3.57
Pr (> F)	0.5403	0.2549	0.0016	0.0932	0.0972	0.2987	0.0340	0.0466
CV (%)	8.95	10.01	7.82	11.44	7.34	9.81	5.06	5.04

Means within the same column in a block, followed by a common letter and/or without letter designations, are not significantly different from each other at 5% level of significance.

3.14 Decay Incidence

Decay incidence is one of the most critical indicators of postharvest quality, as it directly affects marketability, food safety, and consumer acceptance. Table 11 presents the total number of decayed fruits and the decay percentages among bell peppers treated with different combinations of chitosan and plant-based extracts after storage. All treatments began with 10 fruits per treatment, ensuring equal sample sizes for accurate comparison. Table 13 statistical analysis revealed no significant differences among treatments. Despite this, a clear pattern emerged, showing that coating composition influenced the degree of decay. The lowest decay incidence was observed in T2 (6.67%), while higher incidences were recorded in T1 (26.67%), T4 (23.33%), and both T0 and T3 (16.67%). Although not statistically different, these numerical variations suggest that treatment combinations exerted differential effects on disease suppression. As treatment differences were not statistically significant ($p = 0.0567$), specific mechanistic conclusions cannot be drawn. However, the numerical trend toward lower T2 decay is biologically plausible, given that both chitosan and Aloe vera possess antimicrobial properties. Chitosan disrupts microbial cell membranes through its polycationic nature, potentially inhibiting spore germination [21, 36]. Aloe vera complements this by providing additional antimicrobial compounds, such as anthraquinones, acemannan, and saponins, which have been reported to inhibit fungal growth and bacterial proliferation [37]. The higher proportion of aloe vera in T2 likely enhanced this protective effect, contributing to its reduced decay incidence. By comparison, T1 (50 ml of 2% chitosan + 50 ml of 50% aloe vera) showed higher decay incidence, which may be attributed to the lower aloe vera concentration, offering less bioactive antimicrobial protection than T2. Similarly, T3 and T4 (chitosan + moringa) exhibited moderate to high decay levels, indicating that while moringa extracts are rich in antioxidants and have some antimicrobial potential [34], they were less effective than aloe vera in controlling postharvest decay. The control treatment (T0, 2% chitosan alone) provided intermediate protection, consistent with previous studies reporting chitosan's ability to delay microbial infection in fruits [36].

Table 12. VQR and shelf life of the bell pepper fruit (*Capsicum annuum* L.) as influenced by the different chitosan and plant extract-based edible coating.

Treatments	Total No. of Fruits	Decayed Fruits	Decay Incidence
T0- 2% Chitosan	30	5	16.67
T1- 50ml of 2% Chitosan + 50ml of 50% Aloe Vera	30	8	26.67
T2- 33ml of 2% Chitosan + 67ml of 50% Aloe Vera	30	2	6.67
T3- 50ml of 2% Chitosan + 50ml of 50% Moringa Leaf Extracts	30	5	16.67
T4- 33ml of 2% Chitosan + 67ml of 50% Moringa Leaf Extracts	30	7	23.33
F Value			3.31
Pr (> F)			0.0567
CV (%)			40.57

Means within the same column in a block followed by a common letter and/or without letter designations are not significantly different from each other at 5% level of significance.

Table 13. Decay incidence of the bell pepper fruit (*Capsicum annuum* L.) as influenced by the different chitosan and plant extract-based edible coating.

Treatments	Means (Per day)							
	2	4	6	8	10	12	14	16
T0- 2% Chitosan	8.67	8.67	8.47	8.33 ^{ab}	7.80 ^{ab}	7.20 ^{ab}	6.33 ^a	4.40 ^b
T1- 50ml of 2% Chitosan + 50ml of 50% Aloe Vera	8.67	8.53	8.40	8.27 ^{abc}	7.73 ^{abc}	7.00 ^b	6.20 ^{ab}	4.53 ^b
T2- 33ml of 2% Chitosan + 67ml of 50% Aloe Vera	8.67	8.93	8.87	8.67 ^a	7.93 ^a	7.40 ^a	6.67 ^a	5.27 ^a
T3- 50ml of 2% Chitosan + 50ml of 50% Moringa Leaf Extracts	8.33	8.60	7.93	7.87 ^c	7.33 ^c	6.73 ^c	5.73 ^b	4.07 ^b
T4- 33ml of 2% Chitosan + 67ml of 50% Moringa Leaf Extracts	8.67	8.67	8.27	8.07 ^{bc}	7.40 ^{bc}	6.67 ^c	5.73 ^b	4.33 ^b
F Value	0.20	1.04	2.79	4.41	3.64	21.50	7.30	4.15
Pr (> F)	0.9327	0.4337	0.0855	0.0259	0.0443	0.0001	0.0051	0.0308
CV (%)	6.71	2.97	4.18	3.01	3.10	1.65	4.21	8.47

Means within the same column in a block followed by a common letter and/or without letter designations are not significantly different from each other at 5% level of significant.

3.15 pH

The pH values showed significant differences across treatments at all storage stages. Table 14 shows that T3 (50ml of 2% chitosan + 50ml of 20% moringa leaf extract) consistently recorded the highest pH values (4.73–4.90), followed by T4 (33ml of 2% chitosan + 67ml of 20% moringa extract), while T0 (2% chitosan) and aloe vera-based coatings (T1 and T2) exhibited relatively lower values. While all treatments exhibited an increase in pH over time, consistent with the natural metabolism of organic acids into sugars and other compounds during ripening [17], the degree of increase varied. Treatments with aloe vera (T1 and T2) and pure 2% chitosan (T0) maintained relatively lower pH values compared to the moringa-based treatments (T3 and T4). This is notable since lower pH values typically indicate better preservation of fruit acidity and greater metabolic stability, as fruits tend to become more alkaline during ripening and microbial spoilage. Additionally, the T1 and T2 treatments, both incorporating Aloe vera, were more effective at maintaining lower pH, likely due to Aloe vera's antimicrobial properties, which slow microbial activity and acid degradation. Although T3 (50ml of 2% chitosan + 50ml of 20% moringa extract) and T4 (33ml of 2% chitosan + 67ml of 20% moringa extract) recorded the highest pH values, suggesting faster reduction in acidity, the aloe vera-based coatings slowed the rise in pH more effectively. Aloe vera's gel matrix likely acted as a semipermeable barrier, reducing respiration rates and microbial activity, thereby maintaining higher acid content and lower pH levels for a longer duration [32, 33]. Similarly, chitosan itself has been widely reported to delay pH increases by reducing enzymatic and microbial activity in coated fruits [17, 18, 23, 38, 39].

3.16 Total Soluble Solids (TSS)

The TSS values in bell pepper fruits showed no statistically significant differences among treatments across storage time, as summarized in Table 15. Despite this, a clear trend was observed: TSS levels increased until the 10th day, then declined slightly by the final observation. This pattern is typical of ripening fruits, in which starch reserves and complex carbohydrates are hydrolyzed into simple sugars, leading to an increase in soluble solids. At the same time, the subsequent decline reflects their utilization as substrates for respiration and other metabolic processes [17, 23]. Among the treatments, T2 (33 ml of 2% chitosan + 67 ml of 50% aloe vera) recorded the highest final TSS value (5.93 °Brix), followed by T3 (5.67 °Brix). Although not statistically significant, this suggests that a higher proportion of aloe vera gel may have contributed to delayed sugar depletion. Aloe vera gel has been reported to act as a semipermeable barrier that reduces water loss, respiration rate, and oxidative stress, thereby slowing down sugar metabolism [32, 33]. Similarly, chitosan

coatings are known to reduce respiration and ethylene production, thereby helping preserve sugars during storage [36, 40]. The slight variations in TSS among treatments may also be linked to the differing physiological effects of aloe vera and moringa extracts. Aloe vera-based coatings (T1 and T2) tended to support higher sugar retention, while moringa-based coatings (T3 and T4) maintained stable but relatively lower TSS levels. This could be attributed to moringa's higher antioxidant activity, which focuses more on reducing oxidative degradation rather than directly influencing sugar preservation.

Table 14. Initial, 5th day, 10th day and final pH of bell pepper fruit (*Capsicum annuum* L.) as influenced by the different chitosan and plant extract-based edible coating.

Treatments	pH at			
	Initial	5 th day	10 th day	Final
T0- 2% Chitosan	4.57 ^c	4.64 ^c	4.67 ^b	4.73 ^{bc}
T1- 50ml of 2% Chitosan + 50ml of 50% Aloe Vera	4.53 ^c	4.62 ^c	4.68 ^b	4.74 ^{bc}
T2- 33ml of 2% Chitosan + 67ml of 50% Aloe Vera	4.52 ^c	4.59 ^c	4.63 ^b	4.68 ^c
T3- 50ml of 2% Chitosan + 50ml of 50% Moringa Leaf Extracts	4.73 ^a	4.82 ^a	4.85 ^a	4.90 ^a
T4- 33ml of 2% Chitosan + 67ml of 50% Moringa Leaf Extracts	4.66 ^b	4.72 ^b	4.77 ^a	4.83 ^{ab}
F Value	23.26	15.39	12.31	5.75
Pr (> F)	0.0000	0.0003	0.0007	0.0115
CV (%)	0.6964	0.8661	0.9476	1.32

Means within the same column in a block, followed by a common letter and/or without letter designations, are not significantly different from each other at 5% level of significance.

Table 15. Initial, 5th day, 10th day, and final TSS of bell pepper fruit (*Capsicum annuum* L.) as influenced by the different chitosan and plant extract-based edible coating.

Treatments	TSS (°Brix) at			
	Initial	5 th day	10 th day	Final
T0- 2% Chitosan	5.00	6.00	6.00	5.43
T1- 50ml of 2% Chitosan + 50ml of 50% Aloe Vera	4.50	5.30	6.10	5.63
T2- 33ml of 2% Chitosan + 67ml of 50% Aloe Vera	5.30	6.50	6.43	5.93
T3- 50ml of 2% Chitosan + 50ml of 50% Moringa Leaf Extracts	5.20	6.10	6.40	5.67
T4- 33ml of 2% Chitosan + 67ml of 50% Moringa Leaf Extracts	5.10	5.60	6.30	5.63
F Value	0.35	0.78	0.33	0.32
Pr (> F)	0.8384	0.5658	0.8533	0.8571
CV (%)	18.17	15.46	9.18	9.63

Means within the same column in a block, followed by a common letter and/or without letter designations, are not significantly different from each other at 5% level of significance.

3.17 Titratable Acidity (TA)

Table 16 showed that titratable acidity (TA) decreased progressively during storage across all treatments, a trend commonly observed in ripening fruits as organic acids are metabolized into sugars and other compounds through respiration [30]. At the initial stage, TA values ranged between 0.34% and 0.41%, with T0 (2% chitosan) and T2 (33 ml of 2% chitosan + 67 ml of 50% Aloe Vera) recording the highest values (0.41%). By the final day, TA decreased to 0.26–0.30%, with T2 again retaining the highest acid content (0.30%). Statistical analysis revealed significant differences among treatments up to the 10th day, but none at the final measurement. This indicates that coating effects were more evident in the earlier stages of storage, while acid metabolism became uniform toward the end of storage. Aloe vera-based coatings showed contrasting results at different concentrations. T1 (50ml of 2% chitosan + 50ml of 50% aloe vera) consistently recorded the lowest TA values (0.34% initial to 0.26% final), suggesting faster acid utilization and ripening. In contrast, T2 (33ml of 2% chitosan + 67ml of 50% aloe vera) maintained higher TA values, performing comparably to pure chitosan (T0). This suggests that a greater concentration of aloe vera gel enhanced the barrier effect, reduced respiration, and slowed down acid degradation. This is consistent with findings of [33] and [32], who reported that aloe vera gel coatings delay acid loss in grapes and papaya by limiting gas exchange and reducing oxidative stress. Moringa-based coatings (T3 and T4) performed moderately, with final TA values of 0.27% and 0.29%, respectively. While not as high as T2, they maintained better acidity levels than T1. The antioxidant and antimicrobial compounds in moringa, such as flavonoids and phenolics, likely contributed to delaying acid breakdown. However, their effect was less pronounced than that of aloe vera at higher concentrations.

3.18 Relative Humidity and Temperature

Ambient temperature and relative humidity (RH) were monitored twice daily throughout the 16-day storage period at the CTU-Argao BENRC Laboratory under uncontrolled tropical indoor conditions. Mean daily temperature ranged from 30.8°C to 33.2°C (overall mean: 32.1°C), while RH ranged from 66.8% to 72.8% (mean: 69.7%), with afternoon readings consistently warmer and drier than morning readings. These conditions followed a clear, progressive trend over the storage period: temperature increased gradually from Day 0 to Day 16, while RH declined correspondingly, a pattern that closely aligns with the deterioration trends observed across all Study 2 quality parameters. As mean daily temperatures climbed beyond 30°C from Day 6 onward, the accelerated enzymatic activity and respiration rates are reflected in the progressive rise in pH and TSS recorded across treatments, as organic acids were consumed more rapidly and starches converted into soluble sugars. The concurrent decline in RH over the same period exacerbated water loss from fruit surfaces, consistent with the escalating weight loss observed across all treatments, most notably beyond Day 10, when weight loss accelerated sharply across all treatment groups. The Aloe vera-enriched coatings, particularly T2, demonstrated better buffering against worsening ambient conditions, maintaining lower pH, higher titratable acidity, and lower weight loss than Moringa-based treatments, whose weaker film-forming matrices offered less protection as temperature rose and RH fell progressively throughout the storage period. These environmental data, therefore provide critical context for understanding not only the magnitude of quality deterioration observed in Study 2, but also the differential effectiveness of coating treatments over time.

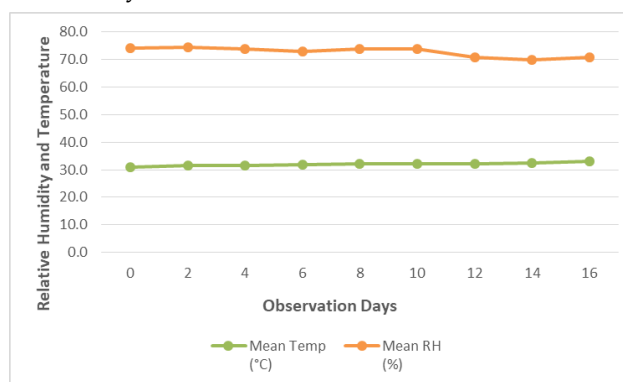


Figure 10. Relative humidity (%) and temperature (°C) during storage of bell pepper (*Capsicum annuum* L.) fruits as influenced by the different chitosan and plant extract-based edible coating.

Table 16. Initial, 5th day, 10th day, and final Titratable Acidity (TA) of bell pepper fruit (*Capsicum annuum* L.)

Treatments	TA (%) at			
	Initial	5 th day	10 th day	Final
T0- 2% Chitosan	0.41 ^a	0.38 ^a	0.33 ^{ab}	0.28
T1- 50ml of 2% Chitosan + 50ml of 50% Aloe Vera	0.34 ^b	0.30 ^c	0.28 ^c	0.26
T2- 33ml of 2% Chitosan + 67ml of 50% Aloe Vera	0.41 ^a	0.38 ^a	0.34 ^a	0.30
T3- 50ml of 2% Chitosan + 50ml of 50% Moringa Leaf Extracts	0.37 ^b	0.35 ^{ab}	0.30 ^{bc}	0.27
T4- 33ml of 2% Chitosan + 67ml of 50% Moringa Leaf Extracts	0.37 ^b	0.34 ^b	0.31 ^{abc}	0.29
F Value	7.94	8.25	4.27	1.87
Pr (> F)	0.0038	0.0033	0.0284	0.1915
CV (%)	4.85	5.71	6.41	7.14

Means within the same column in a block, followed by a common letter and/or without letter designations, are not significantly different from each other at 5% level of significance.

4. Conclusions

This study demonstrates that, among the tested concentrations, 2% chitosan was the most effective for preserving bell pepper quality. It significantly reduced shriveling, maintained firmness, delayed the rise in pH, and completely inhibited decay incidence (0%) relative to the other concentrations, while also maintaining higher titratable acidity and lower total soluble solids—together reflecting delayed ripening and extended shelf life. In Study 2, where chitosan was combined with Aloe vera and Moringa leaf extracts, treatment T2 (33 mL of 2% chitosan + 67 mL of 50% Aloe vera) consistently outperformed the other formulations, producing the lowest weight loss, minimal shriveling, slower firmness loss, superior visual quality ratings, lower decay incidence (6.67%), and higher retention of acidity. Several limitations should be acknowledged to guide future work. First, firmness was assessed using a subjective palpation-based index; instrumental penetrometer measurements should be adopted in future studies. Second, ambient storage temperature and relative humidity were not recorded, and these parameters must be reported to allow meaningful comparison across studies. Third, the Moringa extract concentration requires clarification and consistent labeling throughout (20% vs. 50%). Fourth, the decay-incidence differences in Study 2 were not statistically significant, so antimicrobial claims require validation through microbiological enumeration. Fifth, future studies should include an uncoated negative control in Study 2 to enable direct comparison. Practically, the T2 coating (33 mL of 2% chitosan + 67 mL of 50% Aloe vera) represents a low-cost, farmer-accessible postharvest technology suited to smallholder systems in tropical environments. Further research should assess its economic feasibility, consumer acceptability, and potential for scale-up.

5. Acknowledgments

The authors would like to express their gratitude to the Cebu Technological University - Asturias Campus and the Cebu Technological University - Barili Campus for their support and assistance in making this study a success.

Author Contributions: Conceptualization, A.A.; methodology, A.A., software, A.E.C.; validation, A.A., A.E.C.; formal analysis, A.A.; investigation, A.A., A.E.C.; resources, A.A., A.E.C.; data curation, A.A.; writing—original draft preparation, A.A.; writing—review and editing, A.A., A.E.C.; visualization, A.A.; supervision, A.E.C.; project administration, A.A., A.E.C.; funding acquisition, A.A., A.E.C. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

- [1] Pavlath, A. E.; Orts, W. Edible Films and Coatings: Why, What, and How? In *Edible Films and Coatings for Food Applications*; Embuscado, M. E.; Huber, K. C., Eds.; Springer: New York, NY, 2009; pp 1–23. https://doi.org/10.1007/978-0-387-92824-1_1
- [2] Shafique, M.; Rashid, M.; Ullah, S.; Rajwana, I. A.; Naz, A.; Razzaq, K.; Hussain, M.; Abdelgawad, M. A.; El-Ghorab, A. H.; Ghoneim, M. M.; Shaker, M. E.; Imran, M.; Jbawi, E. A. Shelf Life of Strawberry Affected by Edible Coatings. *Int. J. Food Prop.* **2023**, 26(2), 2995–3012. <https://doi.org/10.1080/10942912.2023.2267794>
- [3] Sharma, S.; Krishna, H.; Barman, K.; Kole, B.; Singh, S. K.; Behera, T. K. Polyamine and Chitosan Effects on Bell Pepper Senescence. *S. Afr. J. Bot.* **2022**, 151, 175–184. <https://doi.org/10.1016/j.sajb.2022.10.016>
- [4] Park, S. I.; Stan, S. D.; Daeschel, M. A.; Zhao, Y. Antifungal Coatings on Strawberries during Cold Storage. *J. Food Sci.* **2005**, 70 (4), M202–M207. <https://doi.org/10.1111/j.1365-2621.2005.tb07163.x>
- [5] Worawut, K.; Phungpis, B.; Kaewkumsan, P.; Noppawan, P. Film Development of Chitosan from Mussel Shells and Pacific White Shrimp Shells. *ASEAN J. Sci. Technol. Rep.* **2024**, 27(4), e254066. <https://doi.org/10.55164/ajstr.v27i4.254066>
- [6] Worawut, K.; Phungpis, B.; Noppawan, P. Valorization of White Shrimp Shell Waste: Development of Chitosan-Based Pellet Feed for Enhanced Nile Tilapia (*Oreochromis niloticus*) Nutrition. *ASEAN J. Sci. Technol. Rep.* **2026**, 29(2), e260098. <https://doi.org/10.55164/ajstr.v29i2.260098>
- [7] Kahramanoglu, I.; Chen, C.; Chen, J.; Wan, C. Chemical Constituents and Antimicrobial Activity of *Aloe vera* Gel. *Agronomy* **2019**, 9, 831. <https://doi.org/10.3390/agronomy9120831>
- [8] Muthmainnah, N.; Solichatun, S. Postharvest Application of Chitosan and Gum Arabic Edible Coating for Chilli. *IOP Conf. Ser.: Mater. Sci. Eng.* **2019**, 633, 012028. <https://doi.org/10.1088/1757-899X/633/1/012028>
- [9] Mahmood, K. T.; Mugal, T.; Haq, I. U. *Moringa oleifera*: A Natural Gift—A Review. *J. Pharm. Sci. Res.* **2010**, 2(11), 775–781.
- [10] Hernandez-Muñoz, P.; Almenar, E.; Ocio, M. J.; Gavara, R. Effect of Calcium Dips and Chitosan Coatings on Postharvest Life of Strawberries. *Postharvest Biol. Technol.* **2006**, 39(3), 247–253. <https://doi.org/10.1016/j.postharvbio.2005.11.006>
- [11] Cruzada, B. S.; Benitez, M. M. Impact of Edible-Based Coatings on Physicochemical Properties of Bitter Gourd. *Sci. Humanit. J.* **2024**, 20, 57–72. <https://doi.org/10.47773/shj.1998.201.4>
- [12] Kasolo, J. N.; Bimenya, G. S.; Ojok, L.; Ochieng, J.; Ogwal-Okeng, J. W. Phytochemicals and Uses of *Moringa oleifera* Leaves. *J. Med. Plants Res.* **2010**, 4(9), 753–757. <https://doi.org/10.5897/JMPR10.128>
- [13] Acedo, A. L., Jr. Postharvest Physiology of Perishable Crops. In *Laboratory Manual in Horticulture 111*; Department of Horticulture, College of Agriculture, Visayas State University: Visca, Baybay, Leyte, Philippines, 1999.
- [14] Falcão-Rodrigues, M. M.; Moldão-Martins, M.; Beirão-da-Costa, M. L. Effect of Edible Coatings on Postharvest Quality of Strawberry. *Food Rev. Int.* **2007**, 23(4), 347–367. <https://doi.org/10.1080/87559120701224843>
- [15] Bautista-Baños, S.; Hernández-López, M.; Bosquez-Molina, E.; Wilson, C. L. Effects of Chitosan and Plant Extracts on Growth of *Colletotrichum gloeosporioides* and Quality of Papaya Fruit. *Crop Prot.* **2003**, 22(9), 1087–1092. [https://doi.org/10.1016/S0261-2194\(03\)00121-0](https://doi.org/10.1016/S0261-2194(03)00121-0)
- [16] Elsabee, M. Z.; Abdou, E. S. Chitosan-Based Edible Films and Coatings: A Review. *Mater. Sci. Eng. C* **2013**, 33(4), 1819–1841. <https://doi.org/10.1016/j.msec.2013.01.010>
- [17] Ali, A.; Maqbool, M.; Alderson, P. G.; Zahid, N. Effect of Gum Arabic as an Edible Coating on Antioxidant Capacity of Tomato (*Solanum lycopersicum* L.) Fruit during Storage. *Postharvest Biol. Technol.* **2013**, 76, 119–124. <https://doi.org/10.1016/j.postharvbio.2012.09.011>
- [18] Ali, A.; Maqbool, M.; Ramachandran, S.; Alderson, P. G. Gum Arabic as a Novel Edible Coating for Enhancing Shelf Life and Improving Postharvest Quality of Tomato (*Solanum lycopersicum* L.) Fruit. *Postharvest Biol. Technol.* **2010**, 58(1), 42–47. <https://doi.org/10.1016/j.postharvbio.2010.05.005>

- [19] Valencia-Chamorro, S. A.; Palou, L.; del Río, M. A.; Pérez-Gago, M. B. Antimicrobial Edible Coatings for Fresh Produce. *Crit. Rev. Food Sci. Nutr.* **2011**, *51*(9), 872–900. <https://doi.org/10.1080/10408398.2010.485705>
- [20] Kumar, L.; Ramakanth, D.; Akhila, K.; Gaikwad, K. K. Edible Films and Coatings for Food Packaging: A Review. *Environ. Chem. Lett.* **2022**, *20*, 875–900. <https://doi.org/10.1007/s10311-021-01339-z>
- [21] Romanazzi, G.; Feliziani, E.; Bautista-Baños, S.; Sivakumar, D. Shelf Life Extension of Fresh Produce by Chitosan Treatment. *Crit. Rev. Food Sci. Nutr.* **2017**, *57*(3), 579–601. <https://doi.org/10.1080/10408398.2014.900474>
- [22] El-Mohamedy, R. S. R.; Rady, M. M. Extending Shelf Life and Maintaining Quality of Sweet Pepper Fruits Using Chitosan and Carboxymethyl Cellulose. *Middle East J. Agric. Res.* **2015**, *4*(1), 19–29. <https://doi.org/10.33687/mejar.004.01.0848>
- [23] Jati, I. R. A.; Setijawaty, E.; Utomo, A. R.; Darmoatmodjo, L. M. Y. Application of *Aloe vera* Gel as Coating Agent to Maintain Tomato Quality. *Coatings* **2022**, *12*(10), 1480. <https://doi.org/10.3390/coatings12101480>
- [24] Dhall, R. K. Advances in Edible Coatings for Fresh Fruits and Vegetables: A Review. *Crit. Rev. Food Sci. Nutr.* **2013**, *53*(5), 435–450. <https://doi.org/10.1080/10408398.2010.541568>
- [25] Wang, F.; Xie, C.; Tang, H.; Hao, W.; Wu, J.; Sun, Y.; Sun, J.; Liu, Y.; Jiang, L. Chitosan Nanofiber Films with Anthocyanins for Active Food Packaging. *Food Hydrocoll.* **2023**, *139*, 108496. <https://doi.org/10.1016/j.foodhyd.2023.108496>
- [26] [26] Ghafoor, K.; Al-Juhaimi, F. Y.; Mohamed Ahmed, I. A.; Babiker, E. E.; Shahzad, S. A.; Alsawmahi, O. N. Effects of Functional Coatings Containing Chitosan, Orange Peel and Olive Cake Extracts on the Quality Attributes of Cucumber during Cold Storage. *Plants* **2022**, *11*(14), 1895. <https://doi.org/10.3390/plants11141895>
- [27] Zarandona, I.; Minh, N. C.; Trung, T. S.; de la Caba, K.; Guerrero, P. Bioactive Release from Chitosan Films with *Aloe vera*. *Int. J. Biol. Macromol.* **2021**, *182*, 1331–1338. <https://doi.org/10.1016/j.ijbiomac.2021.04.200>
- [28] Hemmami, H.; Amor, I. B.; Amor, A. B.; Zeghoud, S.; Ahmed, S.; Alhamad, A. A. Chitosan and Its Derivatives: Sources, Preparation, and Applications. *J. Turk. Chem. Soc. A* **2024**, *11*(1), 341–364. <https://doi.org/10.18596/jotcsa.1336313>
- [29] Chiabrando, V.; Giacalone, G. Shelf-Life Extension of Sweet Cherries Treated with Chitosan and Calcium Chloride. *Postharvest Biol. Technol.* **2011**, *60*(3), 162–168. <https://doi.org/10.1016/j.postharvbio.2010.12.004>
- [30] Serrano, M.; Valverde, J. M.; Guillén, F.; Castillo, S.; Martínez-Romero, D. Use of *Aloe vera* Gel Coating Preserves the Functional Properties of Table Grapes. *Postharvest Biol. Technol.* **2006**, *39*(2), 151–155. <https://doi.org/10.1016/j.postharvbio.2005.11.006>
- [31] Darma, R.; Herliana, O.; Rakhmawati, R. Chitosan Coating in Reducing Postharvest Losses. *J. Agric. Postharvest Res.* **2020**, *17*(3), 211–220. <https://doi.org/10.21082/jtidp.v17n3.2020.p211-220>
- [32] Benítez, S.; Achaerandio, I.; Sepulcre, F.; Pujolà, M. Aloe Vera-Based Edible Coatings Improve the Quality of Minimally Processed Kiwifruit. *Postharvest Biol. Technol.* **2015**, *110*, 86–93. <https://doi.org/10.1016/j.postharvbio.2015.07.014>
- [33] Manoj, H. G.; Sreenivas, K. N.; Shankarappa, T. H.; Krishna, H. C. Effect of Chitosan and *Aloe vera* Coatings on Shelf Life and Quality of Bell Pepper (*Capsicum annuum* L.). *Int. J. Curr. Microbiol. Appl. Sci.* **2016**, *5*(1), 399–405. <https://doi.org/10.20546/ijcmas.2016.501.040>
- [34] Anwar, F.; Latif, S.; Ashraf, M.; Gilani, A. H. *Moringa oleifera*: A Food Plant with Multiple Medicinal Uses. *Phytother. Res.* **2007**, *21*(1), 17–25. <https://doi.org/10.1002/ptr.2023>
- [35] Maan, A. A.; Nazir, A.; Khan, M. K. I.; Ahmad, T.; Zia, R.; Murid, M.; Abrar, M. The Therapeutic Properties and Applications of *Aloe vera*: A Review. *J. Herb. Med.* **2018**, *12*, 1–10. <https://doi.org/10.1016/j.hermed.2018.01.002>

-
- [36] El Ghaouth, A.; Arul, J.; Ponnampalam, R.; Boulet, M. Chitosan Coating Effect on Storability and Quality of Fresh Strawberries. *J. Food Sci.* **1992**, 57(6), 1618–1622. <https://doi.org/10.1111/j.1365-2621.1992.tb08209.x>
- [37] Boudreau, M. D.; Beland, F. A. An Evaluation of the Biological and Toxicological Properties of *Aloe vera*. *J. Environ. Sci. Health C Environ. Carcinog. Ecotoxicol. Rev.* **2006**, 24(1), 103–154. <https://doi.org/10.1080/10590500600614303>
- [38] Ali, A.; Muhammad, M. T. M.; Sijam, K.; Siddiqui, Y. Potential of *Aloe vera* Gel Coating for Delaying Postharvest Browning and Extending Shelf Life of Fresh-Cut Fruits and Vegetables: A Review. *Food Rev. Int.* **2009**, 25(2), 114–128. <https://doi.org/10.1080/87559120802682104>
- [39] Ali, S.; Nawaz, A.; Naz, S.; Ejaz, S.; Maqbool, M.; Siddiqui, M. H.; Kalaji, H. M.; Wróbel, J.; Telesiński, A.; Auriga, A. Hydrogen Sulfide Mitigates Chilling Injury of Postharvest Banana Fruits by Regulating γ -Aminobutyric Acid Shunt Pathway and Ascorbate–Glutathione Cycle. *Front. Plant Sci.* **2022**, 13, 941246. <https://doi.org/10.3389/fpls.2022.941246>
- [40] Zhang, D.; Quantick, P. C. Antifungal Effects of Chitosan Coating on Fresh Strawberries and Raspberries during Storage. *J. Hortic. Sci. Biotechnol.* **1998**, 73(6), 763–767. <https://doi.org/10.1080/14620316.1998.11511025>