Effects of Chitosan and Pomelo (Citrus Maxima var. Magallanes) Peel Extract on the Postharvest Quality and Shelf Life of Bitter Gourd (Momordica Charantia l. var. Galaxy Max F1) under Ambient Condition

Presneil S. Maglasang
Department of Agricultural & Biosystems Engineering, College of Engineering & Geosciences, Caraga State University

Glysdi Care S. McCarthy
Department of Agricultural & Biosystems Engineering, College of Engineering & Geosciences, Caraga State University

Philip Donald C. Sanchez
Department of Agricultural & Biosystems Engineering, College of Engineering & Geosciences, Caraga State University

Febie T. Paglinawan
Department of Plant and Soil Sciences, College of Agriculture and Agri-Industries, Caraga State University

https://doi.org/10.5109/7323251

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 10, pp.112-120, 2024-10-17. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：

Effects of Chitosan and Pomelo (*Citrus maxima* var. Magallanes) Peel Extract on the Postharvest Quality and Shelf Life of Bitter Gourd (*Momordica charantia* l. var. Galaxy Max F1) under Ambient Condition

Presneil S. Maglasang[1], Glysdi Care S. McCarthy[1], Philip Donald C. Sanchez[1,2], and Febie T. Paglinawan[3]
[1]Department of Agricultural & Biosystems Engineering, College of Engineering & Geosciences, Caraga State University, Butuan City, 8600 Philippines
[2]Center for Resource Assessment, Analytics, and Emerging Technologies (CREATE), Caraga State University, Ampayon, Butuan City, 8600 Philippines
[3]Department of Plant and Soil Sciences, College of Agriculture and Agri-Industries, Caraga State University, Ampayon, Butuan City, 8600 Philippines
Corresponding author email: pcsanchez@carsu.edu.ph

Abstract: *Bitter gourd is highly prone to rapid deterioration, exhibiting a shelf life of only 4 to 5 days (d) under ambient conditions. Edible coatings are a promising approach to extending the shelf life of fruits and vegetables by reducing moisture loss and providing an effective barrier against oxygen and microbial growth. Hence, the present study evaluated the effect of chitosan combined with pomelo peel extract coating on the quality and shelf life of bitter gourd under ambient conditions (26-30 °C; RH – 74-86%) using physicochemical assessments. Freshly harvested bitter gourds were randomly divided into five treatments and coated with pomelo peel extract (PPE) and chitosan (CH) at different concentrations: uncoated (T0), LPE1% (T1), CH1% (T2), (LPE + CH) 1% (T3), and (LPE + CH) 2% (T4). A physicochemical assessment composed of non-destructive and destructive tests of the samples was observed every day for a span of 13 days (d) at ambient conditions.*

Keywords: Chitosan, Pomelo Peel Extract; Edible Coating, Storage, Quality Evaluation.

1. INTRODUCTION

Bitter gourd (Momordica charantia L.), locally known as "ampalaya" in the Philippines, is a tropical and sub-tropical vine of the family Cucurbitaceae. Consumption of bitter gourd in recent years has been increased because of its therapeutic benefits [1] high nutritional value [2] and is considered one of the main vegetables of the world and has great trade and industry value [3]. Thus, the consumers demand for quality vegetables has also increased [4] in which they determine by factors like color, firmness, and absence of defects [5]. However, bitter gourd is perishable and is highly susceptible to senescence showing early signs of yellowing, softening, and red pigmentation in the arils if stored under ambient conditions [6] having 4 to 5 days of shelf life [7], [8] Moreover, it typically contains over 90% moisture, making it susceptible to rapid microbiological deterioration, nutritional loss, and swift metabolic changes, similar to other perishable fruits and vegetables [9], [10]. There are various post-harvest treatment options available, with edible coating being recognized as the most effective alternative. Edible coatings made of natural biomolecules appears to be a promising approach used to prolong the appearance and shelf life of fruits and vegetables [11] which leads to reducing postharvest deterioration and preserving the quality for storage [12]. The thin coating will act as a semi-permeable barrier to lower gas exchange, respiration, oxidative reaction rates, moisture, and solute migration [13] and other physiological diseases [14]. However, these substances can influence color, smell, taste, and toxicity in large amounts while being effective as food additives [15]. To evaluate the sensory changes of natural additives, various trials, including combinations of other substances with the use of animal and plant-derived products [16] have been performed. Chitosan is considered as one of the most abundant natural polysaccharides in nature derived from deacetylation of chitin [17] that can be obtained from marine crustacean shells such as crab, crawfish, lobster, and shrimp [18], as well as in the cell walls of fungi and the exoskeletons of insects [19]. While pomelo is considered the largest citrus fruit from the family Rutaceae [20]. According to the study by Zain et al. [21], pomelo peel is the largest and has the thickest peel among all citrus fruits, making up to 30% of the fresh fruit weight. However, Yumnam et al. [22] highlighted that the peels are generally discarded as waste. In addition, Toh et al. [23] stated that the peel of the citrus fruit contains a higher content of antioxidants as compared to its pulp. Thus, the utilization of pomelo peel is highly economical and beneficial. Several research studies have developed an optimized combination of low doses of natural substances. Therefore, to increase the applicability and adequate result, combination of different natural substances is suggested. However, there has been no inclusive research using chitosan combined with pomelo peel extract, and currently, studies on postharvest quality and shelf-life preservation for bitter gourd are limited. Thus, this study will utilize chitosan and pomelo peel extract as edible coatings for bitter gourd.

2. MATERIALS AND METHODS

2.1 Sample Preparation

Bitter gourds (var. Galaxy Max F1) were harvested from the vegetable farm at Barangay Grace Estate, Bayugan City, Agusan del Sur. The gathered samples were immediately transported on the same day to the laboratory room of Caraga State University. Moreover, water soluble chitosan (≥ 90% degree of deacetylation with an average molecular weight of 1.526 kDa) was purchased online from a professional manufacturer of animal and plant extract and other natural ingredient in China. While the pomelo fruit was from Zillovia, Talacogon, Agusan del Sur.

2.2 Pomelo Peel Extraction

Pomelo was manually peeled, and the peels were then thinly sliced and then dried in an oven at 60 °C for about 24 hr to reduce moisture content. After the drying process, the dried peels were converted to powder and extract was prepared by following the procedure detailed by Sabu et al. [24] incorporating novel modifications. Briefly, a 10 g of pomelo peel powder was soaked in 100 ml of ethanol (w/v) for two days. It allows for sufficient time for the extraction of bioactive compounds from the peel, ensuring maximum yield and efficiency in subsequent applications. Two days passed, extract was filtered using Whatman (No.1) filter paper and concentrated under rotary vacuum evaporator at 60 °C for one hr. The extracted pomelo peel was placed in an airtight glass container to minimize the exposure to oxygen, which can lead to oxidation and loss of potency [25].

2.3 Preparation of Coating Solutions

Chitosan (50 g) was dissolved in 5000 mL of distilled water for CH 1%, following the ratio of concentration stipulated by Sabu et al. [24]. For PPE 1%, 50 mL of pomelo peel extract was dissolved in 5000 mL of distilled water. Solutions combining PPE and CH were prepared: (PPE + CH) 1% and (PPE + CH) 2%, where 50% of CH 1% was mixed with 50% of PPE 1% and 100% of CH 1% was mixed with 100% of PPE 1%, respectively. The solutions were stirred using a non-corrosive rod for one hour and left to rest for another hour to allow time for the ingredients to fully dissolve and blend together, ensuring a homogeneous mixture. This resting period also allows any air bubbles introduced during mixing to dissipate, resulting in a smoother application and a more consistent coating on the bitter gourd samples [24,26]. The compositions of the coating solutions for the five treatments are illustrated in Table 1.

Table 1. Compositions of different treatments.

Treatments	Compositions
T0 (Uncoated)	Distilled Water
T1	PPE 1%
T2	CH 1%
T3	(PPE + CH) 1%
T4	(PPE + CH) 2%

CH- Chitosan; **PPE** – Pomelo Peel Extracts; **T0**- Control; **T1** – Treatment 1; **T2**- Treatment 2; **T3**- Treatment 3; and **T4**- Treatment 4.

2.4 Application of Edible Coating to the Samples

The experiment utilized a complete randomized design (CRD). Each treatment was replicated three times, with each replication comprising ten bitter gourd samples for non-destructive testing and another ten for destructive testing, supplemented by an additional 30 samples used as buffers. The samples were randomly assigned to five treatment groups: T0, T1, T2, T3 and T4 and were dipped in the prepared solutions at a solution ratio of 1:2 (w/v) for 2 mins [27]. The coated samples were air-dried at room temperature, and once dried, they were placed on the plastic trays and crates, labeled, and stored on racks. Subsequently, measurements of various physiochemical properties were conducted daily until degradation occurred. From 0 d until 13 d, temperatures range from 26.4 to 29.2 °C, while relative humidity ranges from 74.1% to 86.0%, which falls within the typical range of ambient conditions. List: Number the references (numbers in square brackets) in the list in the order in which they appear in the text.

2.5 Quality Parameters

2.5.1 Non-Destructive Testing

2.5.1.1 Percent Weight Loss

The calculation for percent weight loss (PWL %) was replicated using the equation presented in equation 1 by Prajapati et al. [28]. The samples were weighed every day using the precision electronic balance (Sartorius Precision Electronic Balance, BSA2202S-CW).

$$PWL\ (\%) = \frac{(Initial\ weight - Final\ weight)}{Initial\ weight}\ x\ 100 \qquad (1)$$

2.5.1.2 Visual Quality Rating

The visual quality rating (VQR) was evaluated to assess the fruit's visual appeal during the storage period, as described by [29] in Table 2. The duration required to achieve a VQR 5 rating indicated the potential postharvest viability of bitter gourd stored under ambient conditions.

Table 2. A rating standard developed for the visual quality rating (VQR) of Galaxy F1 cultivar.

VQR Level	Description
9	Excellent, field fresh or no defect
7	Good, defects minor
5	Fair, defects minor, the limit of marketability
3	Poor, defects serious, the limit of edibility
1	Non-edible under usual condition

2.5.1.3 Yellowing Index

Visual observations were conducted for 13 days, with assessments made every day. These evaluations were performed using the Yellowing Index (YI) method by [29], as outlined in Table 3.

Table 3. A rating standard developed for the yellowing index (YI) of Galaxy F1 cultivar [29].

YI	Description
5	Extensive yellowing/discoloration
4	31-50% surface yellowing
3	11-30% surface yellowing
2	1-10% surface yellowing
1	Full green

2.5.1.4 Color

The LS172 colorimeter model was used as the primary tool for detecting color differences in fruit samples, with measurements performed every day until 13 d. Multiple measurements from the three portions were taken to capture any variations. The formula for getting the color gradient is shown in equation 2.

$$\Delta E = \sqrt{(L - L^{*})^2 + (a - a^{*})^2 + (b - b^{*})^2} \qquad (2)$$

Where ΔE – color change; L – lightness; a – greenness to redness; and b- blueness to yellowness.

2.5.2 Destructive Testing

2.5.2.1 Firmness

The firmness was measured using a digital fruit penetrometer, namely the Lutron Precision Fruit Sclerometer, Model FR-5120. The data were represented in kg/cm^2, using a 6 mm probe diameter.

2.5.2.2 pH

Bitter gourds from each treatment were sliced into small pieces. Sliced samples were then blended for homogenization. The fruit's pH value was measured using the digital pH meter (Apera Instruments, PH800 Laboratory Benchtop PH Meter Kit).

2.5.2.3 Total Soluble Solids (TSS)

The TSS content was determined using a Digital Brix and Sucrose Refractometer (Biobase Digital Refractometer, China). The measurement was obtained by placing 1 to 3 droplets of juice onto the instrument's prism and the values were recorded as °Brix.

2.5.2.4 Water Activity

The water activity measurement was conducted using the water activity meter. Each sample, weighing 5 grams for each treatment, was securely inserted and sealed. The sample was left undisturbed for 5 minutes before being carefully analyzed and recorded.

2.6 Statistical Analysis

The measured quality parameters were analyzed using the Statistical Tool for Agricultural Research (STAR) computer software, employing analysis of variance (ANOVA). This allowed for the identification of sources of variation, which included storage days and treatments. To distinguish treatment means at p<0.05, the least significant difference (LSD) was applied, and the coefficient of variation (CV) was derived from the ratio of standard deviation to mean.

3. RESULTS & DISCUSSION

3.1 Non-Destructive Testing

3.1.1 Percent Weight Loss

As revealed in Figure 1, the differences in the weight loss of bitter gourds are influenced by different treatments. It can be clearly seen that T3, exhibited the least weight loss among the other treatments, while T0 experienced the highest weight loss. In just 1 d, T0 began losing weight at a rate of 2.54% and escalated to 29.24% in 8 d before being removed due to bursting and extensive yellowing. Meanwhile, T3 lost weight by 1.88% in 1 d and 18.39% after 8 d. This result was like the study conducted by Bhattacharjee and Dhua [4], as they found out that weight loss in all treated bitter gourds increased during storage. Additionally, influence of storage conditions speeds up degradation. The delayed reduction in weight loss of the treated samples may be attributed to the coating that manipulates levels of oxygen and carbon dioxide within fruits, creating a modified atmosphere that reduces water vapor transmission and, consequently, respiration rates [30]. Thus, the samples under T0 experience even more pronounced weight loss as there is no protective barrier applied, while those coated with edible substances benefit from a shield that mitigates moisture loss and slows the progression of decay. This initial investigation was aligned with the study of Sugumaran et al. [31], as they found that pomelo peel extract contains higher levels of phenolic compounds, flavonoids, antioxidants, and antimicrobial properties, resulting in reduced weight loss in the treated samples. Additionally, Han et al. [32] discussed that chitosan also forms a semipermeable film that regulates gas exchange and reduces transpiration losses, thereby slowing down fruit ripening.

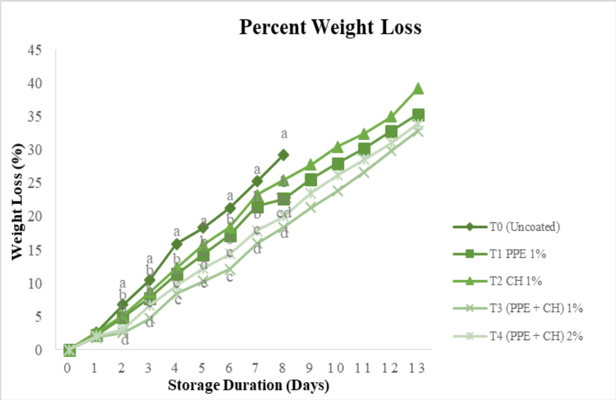

Fig. 1. Percent weight loss of bitter gourd (var. Galaxy Max F1) on different treatments stored at ambient conditions for 13 d. *Treatment means with the same letter are not significantly different at (P<0.05) using the Least Significant Difference (LSD) Test.*

3.1.2 Visual Quality Rating

The results presented in Figure 2 indicate that during the storage period, T0 received the lowest rating, whereas T3 received favorable ratings for appearance, texture, and overall acceptability. It can be gleaned that applying coatings can prolong the visual appearance of fruits by preventing deterioration while stored under ambient conditions [33]. Chitosan is particularly advantageous as it does not promote changes in sensory characteristics when treating perishables [34]. Furthermore, using polysaccharide-based edible coatings has been shown to be an effective method for lengthening the appearance of fruits and vegetables [35]. In addition, citrus byproducts, including the peel, are rich in phenolic compounds like phenolic acids and flavonoids, and these compounds possess antioxidant, anti-inflammatory, and antimicrobial properties, as demonstrated in studies by Nair et al. [36], Mathew et al. [37], Al-Qassabi et al. [38], and Imeneo et al. [39]. The present antimicrobial can inhibit microbial growth during storage; these agents help to maintain appearance and texture. Their study suggests that a particular treatment serves as an alternative for maintaining the natural quality. This claim is consistent with the findings of this study, as both indicate that specific treatments such as pomelo peel extract as part of citrus byproducts, particularly when combined with chitosan, can effectively prolong the visual quality of the bitter gourd.

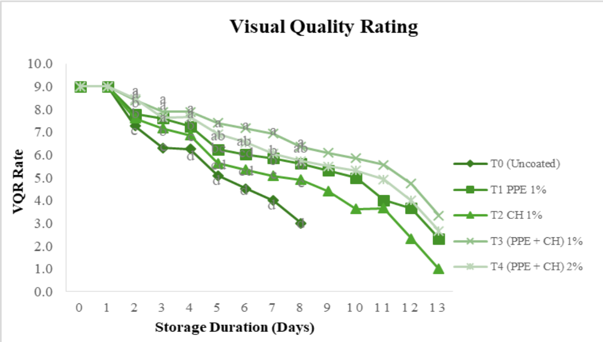

Fig. 2. Visual Quality Rating of bitter gourd (var. Galaxy Max F1) at ambient conditions for 13 d.

3.1.3 Yellowing Index

As depicted in Figure 3, bitter gourd samples treated with four different coatings exhibited delayed color changes. This delay suggests that the coatings applied to the sample slowed down the progression of yellowing, thereby preserving the visual appeal and quality of the fruit. Moreover, on Day 8, T0 exhibited a yellowing index of 5.0, indicating extensive yellowing and discoloration, along with pronounced softening, indicating ripeness. While T1, T2, T3, and T4 have ratings of 3.5, 3.8, 2.6, and 2.9, respectively, indicating a superior preservation of quality when compared to the uncoated. However, the yellowing index of treated bitter gourd declined consistently after 13 days, with ratings dropping to 5.0 for all treatments. Thus, uncoated samples are more susceptible to rapid color changes, leading to an earlier onset of yellowing [40]. In contrast, bitter gourd fruits treated with coatings experience a protective effect that delays the progression of color changes.

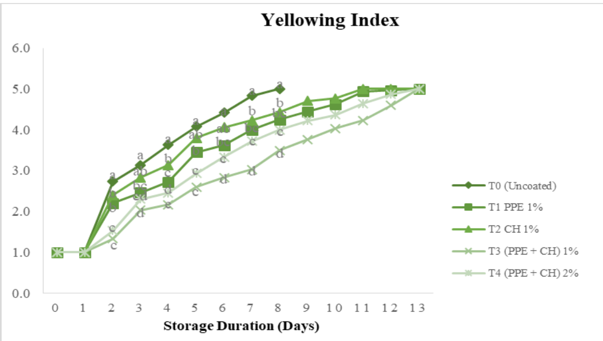

Fig. 3. Yellowing Index of bitter gourd (var. Galaxy Max F1) stored at ambient conditions for 13 d.

3.1.4 Color

Displayed in Figure 4 the color changes of the samples throughout the storage period. By 1 d, mean values of 8.19, 7.13, 7.65, 5.82, and 6.73 were recorded for T0, T1, T2, T3, and T4, respectively. T3 underwent slower changes in color after 13 days of storage, as indicated by slower increases in a and b values as compared to the control ($P < 0.05$). This increasing trend persisted in all treatments until 13 d, except for T0, as the samples were removed on 9 d due to extensive deterioration beyond acceptable levels for analysis. On the contrary, from 9 d to 13 d, no significant differences were observed among the treatments. The loss of surface green color in bitter gourds during storage may be attributed to natural ripening induced by ethylene, coinciding with chlorophyll breakdown and an increase in carotenoid content [41]. However, coated fruits exhibited notably delayed chlorophyll level breakdown compared to uncoated ones. Chlorophyll breakdown is a natural process that occurs during senescence, resulting in the loss of green color and the exposure of other pigments [41]. Bitter gourd, known for its high susceptibility to senescence, is particularly prone to rapid chlorophyll degradation. Citrus extracts provide antioxidants that combat oxidative stress, preserve cellular integrity, and delay the breakdown of chlorophyll [42]. Moreover, the protective barrier created by chitosan helps in reducing moisture loss and gas exchange, which helps to slow down physiological processes associated with senescence [43]. The barriers created by the edible coatings over the surface of the samples help to reduce oxygen exposure and moisture loss, thus slowing down the rate of chlorophyll breakdown and preserving the green color of the produce for an extended period. This finding is supported by Shahid and Abbasi [44] and Koley et al. [45], who demonstrated that coatings help retain the green color.

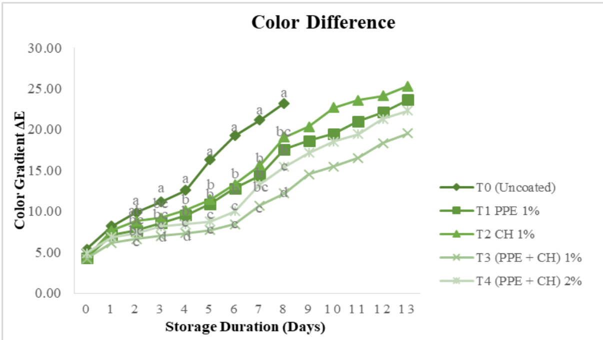

Fig. 4. Color difference of bitter gourd (var. Galaxy Max F1) at ambient conditions for 13 d.

3.2 Destructive Testing

3.2.1 Firmness

The decrease in firmness as the storage period increases as displayed in Figure 5 is attributed to the degradation of soluble pectin by the activity of the endopolygalacturonase enzyme, leading to tissue softening [46]. All samples retained their firmness, with no significant difference ($P < 0.05$) observed on 0 d and 1 d. However, a gradual decrease in firmness was observed from 2 d to 8 d. The T0 exhibited the lowest firmness values, ranging from 1.71 to 0.61, indicating the highest degree of softening throughout the storage period, while the T3 treatment showed the least reduction in firmness, from 1.73 to 1.20, after 8 d. This minimal loss in firmness can be attributed to reduced respiration and transpiration rates, delaying fruit ripening and senescence [47]. On the final day of storage, T3 maintained the highest firmness values compared to other treatment concentrations. This could be attributed to the specific combination of pomelo peel extract and chitosan, effectively decreasing oxygen permeability, transpiration rate, and respiration rate. The two most important factors for fruit and vegetable softening are loss of water due to transpiration, resulting in loss of turgidity, and cell wall breakdown due to enzymatic activities [48]. These results are consistent with the findings of Imeneo et al. [49], who mentioned that applying primarily insoluble pectin and protopectin from citrus fruits to vegetables preserved firmness as the concentration increased. Han et al. [32] stated that applying chitosan coatings to fruits and vegetables maintained lower reduction of firmness during storage. When examining the combined effects of treatments on weight loss and firmness, it becomes evident that moisture loss predominantly influences changes in firmness. This is supported by findings from Paniagua et al. [50], indicating that the trend in fruit firmness changes inversely to that of weight loss.

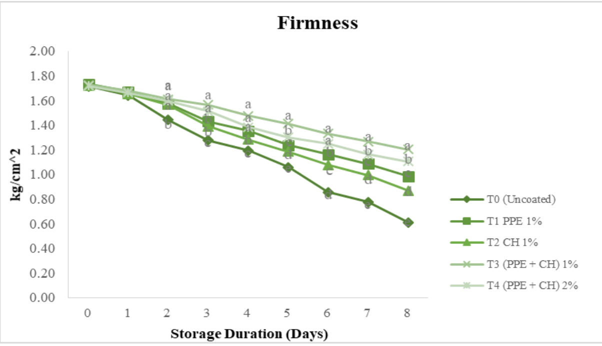

Fig. 5. Firmness of bitter gourd (var. Galaxy Max F1) on different treatments stored at ambient conditions.

3.2.2 pH

The provided data presented in Figure 6 is the pH measurements of five treatments over an 8-day period. pH levels increased in all treatments over the storage period, indicating a decrease in acidity as storage time increased. Specifically, T0 exhibited a notable increase from 5.87 on 2 d to 7.57 on 8 d, while treatment T3 showed a delayed increase from 5.68 on 1 d to 6.63 on 8 d. Previous research by Han et al. [32] has reported similar findings, indicating that T0 samples experienced a greater increase in pH during storage compared to coated samples containing bioactive compounds of pectin and protopectin, commonly found in citrus fruits. An increase in pH in a fruit typically means that the fruit becomes less acidic and more alkaline. This can happen as the fruit ripens, matures, or undergoes certain biochemical changes. Additionally, as highlighted by Imran et al. [51], the increase in pH in fruits may be attributed to biochemical changes occurring during storage, leading to a reduction in fruit acidity. Conversely, a decrease in pH indicates that the fruit becomes more acidic. This could occur due to factors such as microbial activity, or enzymatic reactions leading to the production of organic acids. Hence, this proves that treated samples, especially T3, remain relatively stable or undergo minimal changes compared to T0, as the applied coating acts as a barrier, helping to protect the fruit from external factors that may alter its pH.

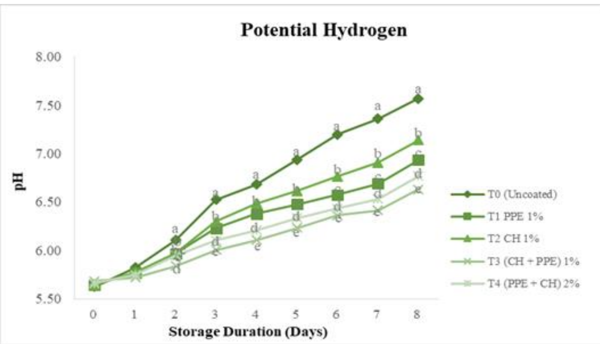

Fig. 6. The pH of bitter gourd (var. Galaxy Max F1) stored at ambient conditions for 13 d.

3.2.3 Total Soluble Solids

Significant differences (Fig. 7) in 2 d to 8 d were observed in all treatments. T0 obtained rapid increase in TSS, which were comparable to other treatments. The slower rate of TSS increase in coated samples is attributed to the reduction of respiratory and physiological ripening activity [52]. A significant difference in trends is observed between T0 and coated samples over a 5-day period, where T0 samples began increasing on the 5th day, reaching a value of 4.64 °Brix, while coated samples exhibited significantly lower TSS values ranging from 0.10 to 0.20 °Brix during the same period. This increase in TSS values may result from the breakdown of polysaccharides into monosaccharides and oligosaccharides, as well as sugar fermentation [53]. Among the treatments, T3 showed lower level of TSS, with a range of 0.07 to 0.14 °Brix per day, surpassing the performance of T0 samples. Ramaswamy et al. [54] found that pectin-based coatings for lime fruit extended shelf life by slowing the trend of TSS compared to uncoated samples, likely due to differences in gas permeability and their impact on respiratory activity [55]. Thus, the coatings effectively slowed down the natural aging process of bitter gourd resulting in a delay in TSS accumulation.

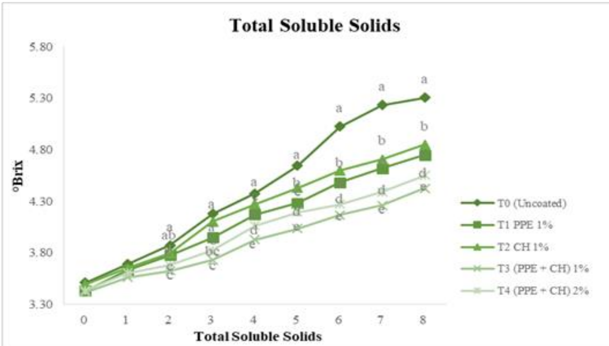

Fig. 7. Total Soluble Solids of bitter gourd (var. Galaxy Max F1) stored at ambient conditions.

3.2.4 Water Activity

Water activity (aw) serves as a superior indicator compared to total moisture for predicting the stability of perishable crops concerning physical characteristics, rates of adverse reactions, and microbial growth [56]. An increase in water activity during storage indicates the degradation of bitter gourd fruit, as microbial contamination or enzymatic activity can cause disruptions in chemical composition, leading to increased water activity levels [57]. As depicted in Figure 8, the water activity of bitter gourd under T0 exhibited the highest levels, while T3 displayed the lowest water activity value among all treatments. Chitosan coating create a protective barrier that defends against bacterial contamination and helps retain moisture, thereby extending the shelf life of fruits and vegetables [58]. According to Tchamba et.al. [59], the banana fruits coated with lemon peel extract shows low moisture adsorption that would be significant to maintain the quality of banana. The increase in water activity observed in the T0 samples could be attributed to greater moisture absorption from the surrounding environment over time.

Thus, without a protective barrier provided by coatings, these samples are more susceptible to moisture uptake, leading to higher water activity levels. Lower water activity reduces the potential risk of microbial growth, thus lowering the potential risk of contamination and spoilage in perishables [60]. This suggests that the T3 concentration effectively prevents rapid increases in the water activity of bitter gourd.

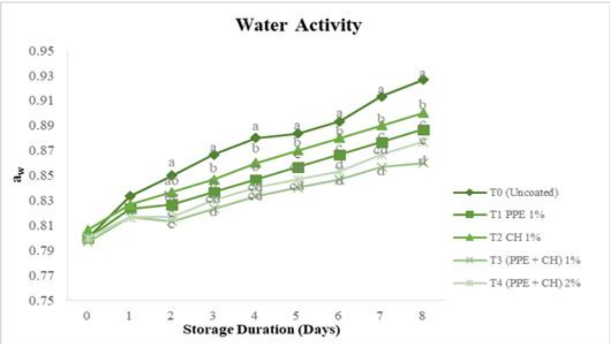

Fig. 8. Water Activity of bitter gourd (var. Galaxy Max F1) on different treatments stored at ambient conditions.

3.2.5 Shelf Life

The shelf life of bitter gourds from different treatments is illustrated in Figure 9. According to Preetha et al. [7], bitter gourd typically has a shelf life of only four days in ambient conditions due to its high moisture content, large surface area relative to volume, thin cuticle, and corrugated fruit surface. This is evident based from the result of the T0. Moreover, Zong et al. [61] reported that when stored under tropical ambient conditions, it exhibit early signs of yellowing, softening, and red pigmentation in the arils. Bitter gourd treated with four different coatings, such as T1, T2, T3, and T4, extended the shelf life by 9 d, 8 d, 12 d, and 10 d, respectively, whereas T0 lasted only 5 d. Among all the treatments, T3 preserved the quality of the bitter gourd for almost 12 days. Research by Aranaz et al. [62] highlights that a low concentration of chitosan solution outperforms a higher concentration, suggesting that chitosan's amino groups undergo protonation in aqueous solutions, releasing hydrogen ions and acidifying the solution. This protonation occurs because the amino groups attract and bind with positively charged ions in the surrounding solution [63]. Similarly, Krongsin et al. [64] found that low concentrations of extracted pectin effectively extend the shelf life of fruits and vegetables, while high concentrations may compromise quality. Additionally, Elbarbary and Mostafa [65] observed that low molecular weight and concentration chitosan exhibit superior preservative and antioxidant activity compared to their high molecular weight and concentration counterparts. Consequently, a lower concentration of the coating mixture is likely to yield more effective results in maintaining crop quality. The research findings align with the present study, where combinations of low concentrations of pomelo peel extract and chitosan demonstrated superior efficacy in prolonging the shelf life of bitter gourd. This emphasizes the importance of carefully optimizing formulation parameters to achieve optimal preservation outcomes [66,67], highlighting that higher concentrations do not necessarily yield optimal results.

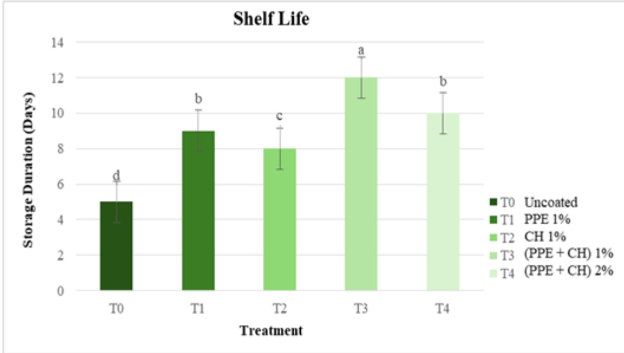

Fig. 9. Shelf life of bitter gourd (var. Galaxy Max F1) on different treatments stored at ambient conditions.

4. CONCLUSION

The formulation of polysaccharide-based edible coatings using water soluble chitosan and pomelo peel extract at various concentrations, such as PPE 1%, CH 1%, (PPE + CH) 1%, and (PPE + CH) 2%, represented by T1, T2, T3, and T4, respectively, has demonstrated significant impacts on the physicochemical properties of bitter gourd under ambient conditions. Coated samples exhibited a slight reduction in firmness, indicating potential softening effects attributed to the presence of PPE. Furthermore, CH exerted pronounced effects on the TSS content and water activity of bitter gourd, leading to a significant increase in TSS levels and a notable reduction in water activity, suggesting improved moisture retention and stability. Thus, the study concludes that optimal concentrations of pomelo (Citrus maxima var. Magallanes) peel extract and water-soluble chitosan, such as (PPE + CH) 1%, have a positive effect on the postharvest quality and extend the shelf life of bitter gourd (Momordica charantia var. Galaxy Max F1).

5. REFERENCES

[1] B. Joseph and D. Jini, "Antidiabetic effects of Momordica charantia (bitter melon) and its medicinal potency," Asian Pac J Trop Dis, vol. 3, no. 2, pp. 93–102, Apr. 2013.

[2] M. Makwana and S. Hati, "Fermented Beverages and Their Health Benefits," in Fermented Beverages, Elsevier, 2019, pp. 1–29.

[3] A. K. Sachan, M. Imtiyaz, M. Shuaib, and D. R. Das, "Momordica charantia as a Potential Medicinal Herb: An Overview," 2015. [Online]. Available: http://wikipedia.org/wiki/Bitter_melon.

[4] D. Bhattacharjee and R. S. Dhua, "Impact of Edible Coatings on the Postharvest Behaviour of Bitter Gourd (Momordica charantia L.) Fruits," Int J Curr Microbiol Appl Sci, vol. 6, no. 3, pp. 336–347, Mar. 2017.

[5] A. Valida et al., "Bitter gourd (Momordica charantia) quality grading at two storage temperatures," Acta Hortic, no. 1213, pp. 293–296, Sep. 2018.

[6] J. May, B. Morales, and F. M. Salas, "Postharvest Quality and Shelflife of Bitter Gourd (Momordica Charantia) at Varying Ultraviolet-C Illumination," 2023.

[7] P. Preetha, N. Varadharaju, and P. Vennila, "Enhancing the shelf life of fresh-cut bitter gourd using modified atmospheric packaging," Afr J Agric Res, vol. 10, no. 17, pp. 1943–1951, Apr. 2015.

[8] R. A. Salas, V. N. Pole, F. M. Salas, and M. A. Quevedo, “Shelf-life and free radical scavenging activity of bittergourd (momordica charantia l.) coated with phytochemical extracts,” Acta Hortic, no. 1088, pp. 247–250, Jun. 2015.
[9] P. S. Chauhan, A. Kumar, C. Nuntadusit, and J. Banout, “Thermal modeling and drying kinetics of bitter gourd flakes drying in modified greenhouse dryer,” Renew Energy, vol. 118, pp. 799–813, Apr. 2018.
[10] A. Ahmad, O. Prakash, and A. Kumar, “Drying kinetics and economic analysis of bitter gourd flakes drying inside hybrid greenhouse dryer,” Environmental Science and Pollution Research, vol. 30, no. 28, pp. 72026–72040, Nov. 2021.
[11] R. Hammoudi, A. Telli, K. O. Nouara, P. Rijo, and Z. Azzouz, “Fruits and Vegetables with a Coating that is Edible: A Review”.
[12] K. Priya, N. Thirunavookarasu, and D. V. Chidanand, “Recent advances in edible coating of food products and its legislations: A review,” J Agric Food Res, vol. 12, p. 100623, Jun. 2023.
[13] S. M. B. and G. P. Panwar, “Permeability of Aloe vera composite coatings and their effect on quality of peeled carrots,” vol. 111, No. 12, pp. 2031–2035, Dec. 2016.
[14] L. Sánchez-González, C. Pastor, M. Vargas, A. Chiralt, C. González-Martínez, and M. Cháfer, “Effect of hydroxypropyl methylcellulose and chitosan coatings with and without bergamot essential oil on quality and safety of cold-stored grapes,” Postharvest Biol Technol, vol. 60, no. 1, pp. 57–63, Apr. 2011.
[15] N.-K. Lee and H.-D. Paik, “Status, Antimicrobial Mechanism, and Regulation of Natural Preservatives in Livestock Food Systems,” Korean J Food Sci Anim Resour, vol. 36, no. 4, pp. 547–557, Aug. 2016.
[16] H. H. Yu, Y.-W. Chin, and H.-D. Paik, “Application of Natural Preservatives for Meat and Meat Products against Food-Borne Pathogens and Spoilage Bacteria: A Review,” Foods, vol. 10, no. 10, p. 2418, Oct. 2021.
[17] A. Bibi, “A review on recent advances in chitosan applications,” Pure and Applied Biology, vol. 10, no. 4, Dec. 2021.
[18] W. Arbia, L. Arbia, L. Adour, and A. Amrane, “Chitin Extraction from Crustacean Shells Using Biological Methods-A Review”.
[19] K. Mohan et al., “Recent insights into the extraction, characterization, and bioactivities of chitin and chitosan from insects,” Trends Food Sci Technol, vol. 105, pp. 17–42, Nov. 2020.
[20] S. Kumar, I. Singh, D. Kohli, J. Joshi, and R. Mishra, “Waste Pomelo (Citrus Maxima) Peels – A Natural Source of Antioxidant and Its Utilization in Peanut Oil for Suppressing the Development of Rancidity,” Current Research in Nutrition and Food Science Journal, vol. 7, no. 3, pp. 800–806, Dec. 2019.
[21] N. F. Mat Zain, “Preparation and Characterization of Cellulose and Nanocellulose from Pomelo (Citrus grandis) Albedo,” J Nutr Food Sci, vol. 05, no. 01, 2014.
[22] M. Yumnam, P. R. Marak, A. K. Gupta, M. A. Rather, and P. Mishra, “Effect of pomelo peel essential oil on the storage stability of a few selected varieties of freshwater fish,” J Agric Food Res, vol. 11, p. 100472, Mar. 2023.
[23] Toh, H. E. Khoo, and A. Azrina, “Comparison of antioxidant properties of pomelo [Citrus Grandis (L) Osbeck] varieties,” 2013.
[24] S. Sabu, T. Ashita, and S. Stephy, “Chitosan and lemon peel extract coating on quality and shelf life of yellowfin tuna (Thunnus albacares) meat stored under refrigerated condition,” Indian Journal of Fisheries, vol. 67, no. 1, pp. 114–122, 2020.
[25] N. Hasan Khan, “Phytochemical screening, antimicrobial and antioxidant activity determination of citrus maxima peel,” Pharm Pharmacol Int J, vol. 6, no. 4, Jul. 2018.
[26] K. Owusu-Akyaw Oduro, “Edible Coating,” in Postharvest Technology - Recent Advances, New Perspectives and Applications, IntechOpen, 2022.
[27] R. Elsabagh et al., “Chitosan edible coating: a potential control of toxic biogenic amines and enhancing the quality and shelf life of chilled tuna filets,” Front Sustain Food Syst, vol. 7, May 2023.
[28] U. Prajapati, R. Asrey, E. Varghese, and R. R. Sharma, “Effects of calcium lactate on postharvest quality of bitter gourd fruit during cold storage,” Physiology and Molecular Biology of Plants, vol. 27, no. 8, pp. 1811–1821, Aug. 2021.
[29] A. Valida et al., “Bitter gourd (Momordica charantia) quality grading at two storage temperatures,” Acta Hortic, no. 1213, pp. 293–296, Sep. 2018.
[30] V. B. TN. Arumugam, “Wax coating affects postharvest shelf-life of non-cooled sweet pepper,” Journal of Spices and Aromatic Crops, vol. 23, no. 1, pp. 98–101, Sep. 2014.
[31] K. Sugumaran et al., “Optimization of antimicrobial activity of flavonoid extracts from pomelo (Citrus grandis) peel as food wrap,” 2017, p. 020089.
[32] C. Han et al., “Effects of chitosan coating on postharvest quality and shelf life of sponge gourd (Luffa cylindrica) during storage,” Sci Hortic, vol. 166, pp. 1–8, Feb. 2014.
[33] T. T. Pham, L. L. P. Nguyen, M. S. Dam, and L. Baranyai, “Application of Edible Coating in Extension of Fruit Shelf Life: Review,” Agri Engineering, vol. 5, no. 1, pp. 520–536, Mar. 2023.
[34] A. G. Inanli, E. T. A. Tümerkan, N. El Abed, J. M. Regenstein, and F. Özogul, “The impact of chitosan on seafood quality and human health: A review,” Trends Food Sci Technol, vol. 97, pp. 404–416, Mar. 2020.
[35] R. G. Cruz-Monterrosa, A. A. Rayas-Amor, R. M. González-Reza, M. L. Zambrano-Zaragoza, J. E. Aguilar-Toalá, and A. M. Liceaga, “Application of Polysaccharide-Based Edible Coatings on Fruits and Vegetables: Improvement of Food Quality and Bioactivities,” Polysaccharides, vol. 4, no. 2, pp. 99–115, Mar. 2023.
[36] “Antioxidant and antimicrobial activities of citrus lemon peels encapsulated in pva,” Carpathian Journal of Food Science and Technology, pp. 110–125, Jul. 2019.
[37] B. B. Mathew, D. Shajie, N. Wadhwa, N. B. Krishna Murthy, T. P. Krishna Murthy, and M. Rashmi, “Comparative antioxidant efficacy of Citrus limonum

pulp and peel – An in vitro study," Drug Invention Today, vol. 5, no. 4, pp. 296–301, Dec. 2013.
[38] J. S. A. Al-Qassabi, A. M. Weli, and M. A. Hossain, "Comparison of total phenols content and antioxidant potential of peel extracts of local and imported lemons samples," Sustain Chem Pharm, vol. 8, pp. 71–75, Jun. 2018.
[39] V. Imeneo, R. Romeo, A. Gattuso, A. De Bruno, and A. Piscopo, "Functionalized Biscuits with Bioactive Ingredients Obtained by Citrus Lemon Pomace," Foods, vol. 10, no. 10, p. 2460, Oct. 2021.
[40] A. Rubio et al., "Cytosolic and Plastoglobule-targeted Carotenoid Dioxygenases from Crocus sativus Are Both Involved in β-Ionone Release," Journal of Biological Chemistry, vol. 283, no. 36, pp. 24816–24825, Sep. 2008.
[41] N. Yamauchi, Y. Tokuhara, Y. Ohyama, and M. Shigyo, "Inhibitory effect of sucrose laurate ester on degreening in Citrus nagato-yuzukichi fruit during storage," Postharvest Biol Technol, vol. 47, no. 3, pp. 333–337, Mar. 2008.
[42] M. Saleem et al., "Investigation of antioxidant and antibacterial effects of citrus fruits peels extracts using different extracting agents: Phytochemical analysis within silico studies," Heliyon, vol. 9, no. 4, p. e15433, Apr. 2023.
[43] H. Dong, L. Cheng, J. Tan, K. Zheng, and Y. Jiang, "Effects of chitosan coating on quality and shelf life of peeled litchi fruit," J Food Eng, vol. 64, no. 3, pp. 355–358, Sep. 2004.
[44] M. Nasir Shahid and N. Akhtar Abbasi, "Effect of bee wax coatings on physiological changes in fruits of sweet orange cv. 'blood red,'" 2011.
[45] T. K. , A. R. , P. R. K. , and S. D. V. K. Koley, "Shelf-life extension in pointed gourd (Trichosanthes dioica Roxb.) by post-harvest Application of sodium hypochlorite, potassium metabisulphite and carnauba wax," vol. 46, no. 6, pp. 581–584, Nov. 2009.
[46] K. Kaur and W. S. Dhillon, "Influence of maturity and storage period on physical and biochemical characteristics of pear during post cold storage at ambient conditions," J Food Sci Technol, vol. 52, no. 8, pp. 5352–5356, Aug. 2015.
[47] S. L. S. Bico, M. F. J. Raposo, R. M. S. C. Morais, and A. M. M. B. Morais, "Combined effects of chemical dip and/or carrageenan coating and/or controlled atmosphere on quality of fresh-cut banana," Food Control, vol. 20, no. 5, pp. 508–514, May 2009,
[48] Z. Hussein, O. A. Fawole, and U. L. Opara, "Harvest and Postharvest Factors Affecting Bruise Damage of Fresh Fruits," Hortic Plant J, vol. 6, no. 1, pp. 1–13, Jan. 2020.
[49] V. Imeneo, R. Romeo, A. Gattuso, A. De Bruno, and A. Piscopo, "Functionalized Biscuits with Bioactive Ingredients Obtained by Citrus Lemon Pomace," Foods, vol. 10, no. 10, p. 2460, Oct. 2021.
[50] A. C. Paniagua, A. R. East, J. P. Hindmarsh, and J. A. Heyes, "Moisture loss is the major cause of firmness change during postharvest storage of blueberry," Postharvest Biol Technol, vol. 79, pp. 13–19, May 2013.
[51] K. R. & A. M. Imran A., "Effect of added sugar at various concentration on the storage stability of guava pulp.," vol. 16, no. 1, pp. 89–93, 2000.
[52] S. M., A. S. , S. W. Yimenu, "Effect of bee wax and linseed oil coatings and frequency of dipping on the biochemical and organoleptic quality of fresh orange juice (Citrus sinensis cv. Valencia) ," Jan. 2017.
[53] S., M. M. A., & N. S. Wisal, "Storage studies of strawberry juice with TSS of 7.5 and 20.5o Brix preserved with sodium benzoate and potassium sorbate stored at ambient temperature. ," International Journal of Basic and Applied Science, pp. 36–42, 2014.
[54] M. Moalemiyan and H. S. Ramaswamy, "Quality Retention and Shelf-life Extension in Mediterranean Cucumbers Coated with a Pectin-based Film," J Food Res, vol. 1, no. 3, p. 159, Jul. 2012.
[55] C. Han, Y. Zhao, S. W. Leonard, and M. G. Traber, "Edible coatings to improve storability and enhance nutritional value of fresh and frozen strawberries (Fragaria × ananassa) and raspberries (Rubus ideaus)," Postharvest Biol Technol, vol. 33, no. 1, pp. 67–78, Jul. 2004.
[56] R., P. S. Radev, "Water activity (aw) of starch edible films.," pp. 33–35, 2015.
[57] S. M. Alzamora, M. S. Tapia, A. López-Malo, and J. Welti-Chanes, "The control of water activity," in Food Preservation Techniques, Elsevier, 2003, pp. 126–153.
[58] R. Ahmad Shiekh, M. Ahmad Malik, S. Ahmed al-ThabaiTi, and M. Ahmad Shiekh, "Chitosan as a Novel Edible Coating for Fresh Fruits," 2013.
[59] E.-I. Ngoko Tchamba, T. Tybussek, P. Muranyi, V. F. Nguetsop, J. Aghofack-Nguemezi, and W. Schwab, "The Combined Effect of Lemon Peel Extract and Calcium Chloride on the Physical and Biochemical Quality Parameters of the Dessert Banana (Musa acuminata var. Dwarf Cavendish) Fruit," Agriculture, vol. 14, no. 2, p. 222, Jan. 2024.
[60] L. R. BEUCHAT et al., "Low--Water Activity Foods: Increased Concern as Vehicles of Foodborne Pathogens," J Food Prot, vol. 76, no. 1, pp. 150–172, Jan. 2013.
[61] R.-J. Zong, L. Morris, and M. Cantwell, "Postharvest physiology and quality of bitter melon (Momordica charantia L.)," Postharvest Biol Technol, vol. 6, no. 1–2, pp. 65–72, Jun. 1995.
[62] I. Aranaz et al., "Chitosan: An Overview of Its Properties and Applications," Polymers (Basel), vol. 13, no. 19, p. 3256, Sep. 2021.
[63] Q. Z. Wang et al., "Protonation constants of chitosan with different molecular weight and degree of deacetylation," Carbohydr Polym, vol. 65, no. 2, pp. 194–201, Jul. 2006.
[64] P. Williams and G. Phillips, Eds., Gums and Stabilisers for the Food Industry 17. Cambridge: Royal Society of Chemistry, 2014.
[65] A. M. Elbarbary and T. B. Mostafa, "Effect of γ-rays on carboxymethyl chitosan for use as antioxidant and preservative coating for peach fruit," Carbohydr Polym, vol. 104, pp. 109–117, Apr. 2014.
[66] K. N. Sindol, A. S. T. Gadat, J. J. J. Sanchez, P. D. C. Sanchez, Development and Characterization of Briquettes made from Unsalable Banana Peels: A Preliminary Evaluation, International Exchange and

Innovation Conference on Engineering and Sciences (IEICES), vol. 8, pp. 265-270, 2022.
[67] M. C. Alvarado, S. G. N. Polongasa, P. D. C. Sanchez, A Preliminary Evaluation on the Development of Edible Drinking Straw from Guso (*Eucheuma cottonii*) Seaweeds, International Exchange and Innovation Conference on Engineering and Sciences (IEICES), vol. 9, pp. 51-58, 2023.