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Preparation of natural polymer coating incorporating silver nanoparticles to extend shelf life of passion fruit

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Abstract. Passion fruit is highly perishable because of its vigorous metabolic activity after harvest. Therefore, "green" preservation using safe natural polysaccharides as functional coatings is of significant research interest. This study investigated the combined effects of chitosan and silver nanoparticle coatings at varying concentrations on the quality and shelf life of passion fruit. The results show that the appropriate chitosan concentration to prolong the preservation time was 1%. After 20 days of storage at 25 ± 2 °C, the weight loss was 19.59%. The total yeast and mold, soluble solids, acidity, and vitamin C content were 8.1×10^6 CFU/g, 14.5 °B_x, 6.31%, and 0.1583 mg/g, respectively. The coating from chitosan 1%-silver nanoparticles 5 mg/L solution was the most effective in the weight loss of the passion fruit at 17.4%, and the fruit peel colour changed insignificantly. The treated samples exhibited a total yeast and mold count of 1.3×10^5 CFU/g, soluble solids of 14.83 °B_x, the acidity of 6.59%, and vitamin C content of 0.1841 mg/g. Interestingly, no silver nanoparticle residues were detected in the fruit flesh. These findings provided a scientific basis and demonstrated the practical potential of silver nanoparticle-chitosan coatings for effective fruit preservation.

Keywords: passion fruit, chitosan, silver nanoparticles, preservation

1 Introduction

Passion fruit (*Passiflora edulis*) is an economically significant and valuable tropical fruit crop cultivated in Vietnam. The fruit is a rich source of organic acids, minerals, vitamins, and antioxidant compounds, contributing to its characteristic organoleptic properties and offering various health-promoting benefits. However, passion fruit exhibits a climacteric respiratory pattern, leading to an accelerated rate of postharvest physiological metabolism. This results in a high degree of perishability and susceptibility to spoilage through dehydration, microbial proliferation, oxidative processes, peel shrinkage, etc. [1]. As a result, the limited postharvest shelf life severely compromises its economic viability [2].

Current postharvest research focuses on developing strategies to extend the storage time of passion fruit and maintain its quality by controlling spoilage during storage and consumption. Primary approaches include the application of chemical fungicides and low-temperature storage, which aims to reduce enzymatic activity [3]. However, synthetic chemical fungicides are toxic and can be bioaccumulated in fruits, causing harm to humans and the environment [4]. Additionally, most tropical fruits are sensitive to low temperatures, leading to chilling injury. Therefore, “green” preservation methods for passion fruit were an

attractive research direction. Functional coatings with natural polymers such as polysaccharides, proteins, and lipids, have attracted considerable attention from researchers and have proven to be a "green" and promising preservation method for preserving fresh fruit and vegetables owing to their friendly environment, biocompatibility, and biodegradability. The natural polymer—chitosan—effectively preserves fruits and vegetables by forming coatings, inhibiting polyphenol oxidations, and reducing passion fruit respiration, which prolongs its freshness [4]. Despite chitosan's inherent antibacterial properties, its limited potency prompted the addition of silver nanoparticles to the coating membrane in this study, aiming to improve passion fruit preservation efficiency. By providing a broad antibacterial spectrum, silver nanoparticles, when incorporated into coatings, augment antimicrobial efficacy and extend the postharvest shelf life of the passion fruits. Moreover, the residual silver content of the treated fruit flesh was also determined.

2 Materials and methods

2.1 Materials

Passion fruits were provided by Dung Ha Agricultural Products Co., Ltd., Ho Chi Minh City, Vietnam. The selected passion fruits, 60–80 g/fruit, were classified uniformly in size and colour. Chitosan had a molecular weight of ~600,000 g/mol with a deacetylation degree of ~85%. Silver nanoparticles with a concentration of 1,000 mg/L and particle size of 10–15 nm were a product of the Research and Development Center for Radiation Technology, Vietnam Atomic Energy Institutes.

2.2 Preparation of preserving passion fruit with chitosan coating at different concentrations

The preparation of chitosan-based coating solutions for passion fruit preservation is described in Fig. 1. Chitosan was dissolved in lactic acid and stirred for 2 hours, followed by overnight storage. The resulting solutions were then filtered through a 100-mesh sieve to remove undissolved parts and filled with distilled water to achieve final chitosan concentrations of 1, 1.5, and 2% (w/v). Pre-selected passion fruits were dipped in the solutions for 10 seconds. Afterwards, the fruits were air-dried and stored at 25 ± 2 °C and 75–80% relative humidity for subsequent experiments.

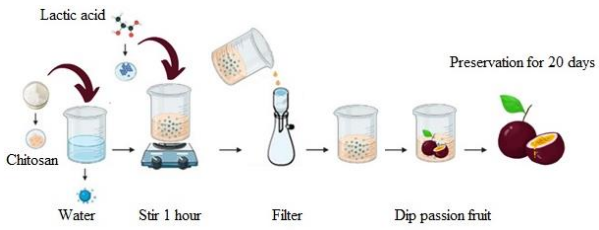

Fig. 1. Peparation of coating membranes for preserving passion fruit

2.3 Preparation of preserving passion fruit with chitosan coating containing silver nanoparticles at different concentrations

Upon determining the appropriate chitosan concentration in the solution, silver nanoparticles were added into the solution with final concentrations of 1, 3, and 5 mg/L (≈ppm). The passion fruit was then processed and preserved, as detailed in Section 2.2.

2.4 Characterisation analysis

Fruit peel colour was assessed by measuring L* (brightness), a* (redness/greenness), and b* (yellowness/blueness) values with a portable colourimeter (Konica Minolta, Chroma Meter CR-400, Japan).

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The weight loss was evaluated by monitoring fruit weight throughout the storage period. The percentage of weight loss (W_L) was calculated according to Eq. (1) as follows:

$$W_L(\%) = \frac{W_0 - W_t}{W_0} \times 100 \quad (1)$$

where W_0 and W_t are the initial weight (g) and the weight of passion fruit at a given storage time (g), respectively.

The total soluble solids (TSS) were determined using a TI-RBX0032 handheld refractometer (Trans Instruments Pte Ltd., Singapore).

The vitamin C content was determined by using AOAC Official Method 967.21 (2016), which employed the 2,6-dichloroindophenol titrimetric method.

The acidity of fruits, expressed as titratable acidity, was determined via titration with a 0.1 N sodium hydroxide (NaOH) solution using AOAC Official Method 942.15.

The total yeast and mold counts were determined by using the Colony Count Technique, following the procedures outlined in ISO 21527-2:2008.

The silver residues in fruit flesh were quantified by using inductively coupled plasma atomic emission spectrometry (ICP-OES) with Test Method CASE.TN.0131 (2020), adapted from EPA Method 200.7.

The statistical analysis of the experimental data was performed with Microsoft Excel 2019. The IBM SPSS Statistics 20 tool was applied to evaluate ANOVA. The measured values were reported as mean ± standard deviation (SD). The significant differences between groups were confirmed with Duncan's multiple range test at a probability level of $p < 0.05$.

3 Results and discussions

3.1 Effect of chitosan concentration on passion fruit peel colour

The L* values of the passion fruit peel decreased in all samples throughout the storage period (Fig. 2a), indicating increased browning. At the end of the storage period, the control group exhibited the lowest L* value (21.35), while the 1% chitosan-coated group had the highest (25.60), with a statistically significant difference. As shown in Fig. 2b, the initial a* value for the control sample was 18.57, decreasing to 8.96 after 20 days. On the 20th day, the 1% chitosan-coated sample maintained the highest a* value (13.55), significantly different from that of other treatments. Similarly, the initial b* value for the 1% chitosan-coated sample was 6.51, decreasing to 5.87 at the end of the storage period. In contrast, the control sample showed the lowest b* value (5.10) at the end of the storage period (Fig. 2c). The observed decrease in L*, a*, and b* values likely resulted from anthocyanin degradation during fruit ripening [3].

The passion fruits treated with a chitosan coating can slow down respiration and reduce ethylene production, altering the internal environment of the fruit. This slowdown in ripening and ageing processes leads to less colour change of the fruit. Our findings align with the study on papaya peel preservation [4]. Accordingly, chitosan coating helps to slow down the discolouration of this fruit. Slow anthocyanin synthesis has been observed in other fruits treated with chitosan coating, including papaya, strawberries, lychees, sweet potatoes, bell peppers, pears, and mangoes [5]. Because of the passion fruit signs of damage after 20 days of storage (Fig. 3), the experiments were terminated at this time.

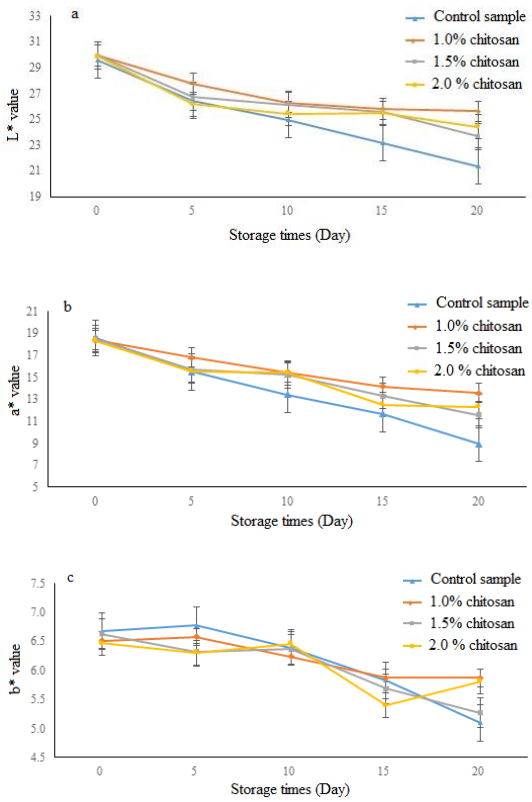

Fig. 2. Effect of chitosan concentration on L* (a), a* (b), and b* (c) values of passion fruit peel

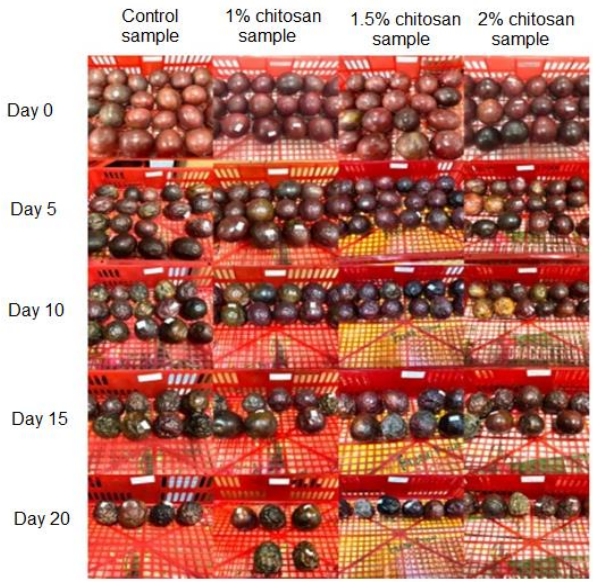

Fig. 3. Colour changes of passion fruit peel dipped in chitosan solutions of different concentrations during 20 days of storage

3.2 Effect of chitosan concentration on weight loss, total soluble solids, total acid, and total vitamin C of passion fruit

The weight loss during storage and ripening is an important parameter that determines the nutritional and commercial value of the fruit [6]. The weight loss of passion fruit is affected by both storage time and the preservation method. The effect of chitosan coating with different concentrations on passion fruit weight loss during preservation is illustrated in Fig. 4a. Statistically significant differences ($p < 0.05$) in weight loss on the same day are expressed with different letters (a–d) above the columns. Similarly, the difference in weight loss over different preservation periods for the same chitosan concentrations is indicated by different letters (u–z) to the right of the rows. After 20 days of preservation, the 1% chitosan solution induced the lowest weight loss (19.59%) compared with other treatments, while the control group showed the highest weight loss (25.51%).

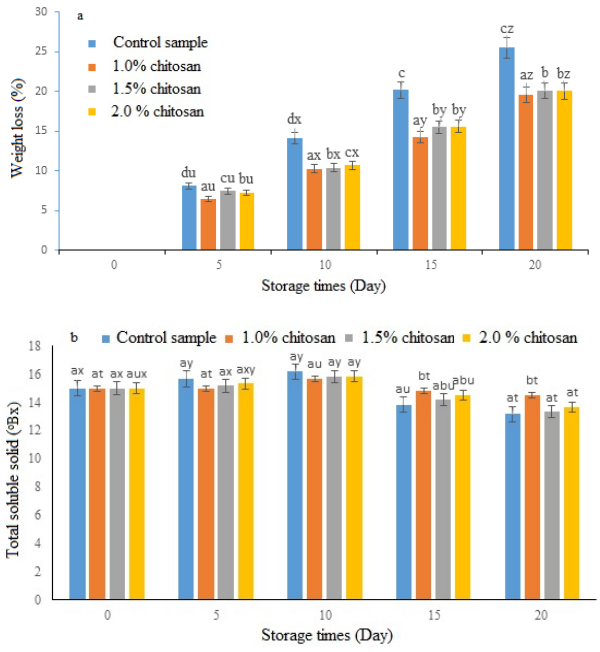

Fig. 4. Effect of chitosan concentration on weight loss (a) and total soluble solids (b) of passion fruit during 20 days of storage

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The weight loss with increasing storage time was observed in all the treatments. The control sample exhibited the most significant weight loss, which can be influenced by the easy formation of reactive oxygen species and high ripening rate [7]. A lower weight loss was observed in chitosan-coated samples. Chitosan coating acts as a semi-permeable membrane against O_2, CO_2, and moisture, thereby reducing respiration, water loss, and the formation of reactive oxygen species [8]. Similar results were reported in the case of dragon fruit [9], indicating that the fruit coated with a 4% chitosan solution had the lowest weight loss of 1.56% compared with that of the control sample (10.56%) after 8 days of storage.

The total soluble solids were used as a parameter to determine the stage of fruit ripening as well as the sweetness of the fruit [10]. Fig. 4b shows the TSS of the passion fruits during 20-day storage. The values with different letters (a–b) indicate statistically significant differences across the columns (chitosan concentrations). Values with different letters (t–y) indicate statistically significant differences across rows (days). In all the treatments, TSS increased for the first 10 days of storage and gradually decreased in the next period. This initial increase in TSS likely occurred because hydrolytic enzymes are more active during the early stages of fruit ripening, leading to an accumulation of TSS. Subsequently, as the fruit approaches spoilage, these dry substances are consumed through metabolic processes, causing TSS to decrease towards the end of the storage period. After 20 days, the control sample exhibited the lowest TSS (13.17 °Bx). Conversely, the highest TSS value (14.5 °Bx) was observed in the passion fruit samples treated with 1% chitosan. Thus, the passion fruits coated with chitosan membrane slowed down the ageing process and controlled the rapid conversion of starch into sugar, resulting in a low ripening rate. Chitosan forms a semi-permeable coating on the surface of the passion fruit, which helps regulate its internal environment by reducing O_2 and/or increasing CO_2 concentrations. These changes can inhibit the respiration and metabolic activities in the fruits [11]. Similarly, chitosan-coated papaya fruits reduced the rate of TSS change after 5 weeks of storage [4]. Similar results were also reported in studies on mango and bananas, where the TSS values increased more slowly in the fruit samples treated with chitosan coating [12]. These findings suggested that chitosan not only extends the shelf life of these fruits but also helps maintain their quality over time. Therefore, treating with chitosan could be a valuable technique for enhancing the marketability of tropical fruits. Fig. 5a shows that the total acid content in all the samples tends to decrease with storage time. The values with different lowercase letters (a–d) indicate statistically significant differences ($p < 0.05$) across the columns (chitosan concentrations), while the values with the different lowercase letters (x–u) indicate differences across the rows (storage days). The initial total acid content of the passion fruit samples was 8.15%. After 20 days of storage, this value decreased to 4.63% (control), 6.31% (1% chitosan), 5.97% (1.5% chitosan), and 5.58% (2% chitosan). This decrease can be attributed to the utility of acid as a substrate during fruit respiration [13]. Furthermore, the increase in the Brix/Acid ratio as the fruit ripens also contributes to the reduction in the total acid content [10]. A similar decrease in total acid content was observed in a study on chitosan-coated pink-fleshed dragon fruit (*Hylocereus* spp.) stored at ambient temperature [9].

Fig. 5b shows the vitamin C content of the passion fruits during the 20-day storage. The values marked with different lowercase letters (a–d) indicate statistically significant differences ($p < 0.05$) between columns (chitosan concentrations), while values marked with different letters (x–u)

indicate differences between rows (storage days). As shown in Fig. 5b, the vitamin C content of all the samples generally decreased over the storage period. The initial vitamin C content of the passion fruit flesh was 26.7 mg/100 g. After 20 days of storage, the control sample exhibited the lowest content (13.33 mg/100 g), whereas the sample treated with a 1% chitosan solution retained the highest content (15.83 mg/100 g). This decrease in vitamin C content is likely due to the natural degradation of ascorbic acid during fruit ripening. In addition, exposure to light and high temperatures can accelerate vitamin C loss. Furthermore, oxygen also plays a significant role in vitamin C loss [10]. Our findings align with a study evaluating the vitamin C content of chitosan-coated blueberries, where the resulting content slightly decreased and maintained at 7.34 mg/100 g of the fruit flesh for 8 days at room temperature [14].

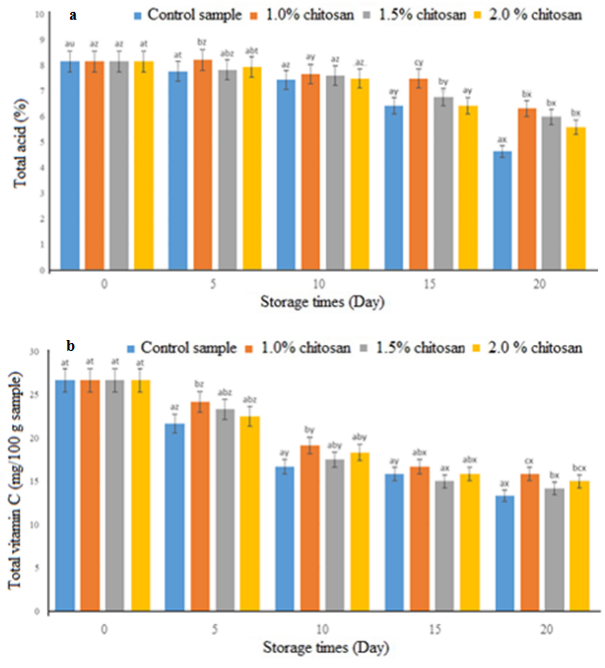

Fig. 5. Effect of chitosan concentration on total acidity (a) and total vitamin C content (b) of passion fruit during 20 days of storage

3.3 Effect of chitosan concentration on total yeast and mold

The number of yeast and mold on the surface of the passion fruit increased gradually in all the samples during storage. However, the control experienced a rapid proliferation of these microorganisms, reaching densities of 3.3×10^5 CFU/g after 10 days and 3.4×10^7 CFU/g after 20 days. Conversely, the application of chitosan effectively inhibited yeast and mold growth in the treated samples, resulting in a 2–5 day extension of their storage life compared with the control. The 2% chitosan coating proved the most effective in suppressing microbial growth (Table 1). This ability of chitosan coatings to inhibit microorganism growth, thereby reducing spoilage and extending storage, aligns with the findings of a study on post-harvest preservation of dragon fruit [15].

Table 1. Effect of chitosan concentration on total yeast and mold counts

Chitosan concentration (%)	The total yeast mold (CFU/g)				
	Day 0	Day 5	Day 10	Day 15	Day 20
0	ND(*)	7.0_x10^1	3.3_x10^5	9.0_x10^6	3.4_x10^7
1	ND	3.5_x10^1	1.9_x10^3	3.2_x10^5	8.1_x10^6
1.5	ND	3.8_x10^1	1.2_x10^3	2.5_x10^5	7.6_x10^6
2	ND	2.6_x10^1	1.0_x10^4	6.0_x10^5	5.5_x10^6

*ND: Not detected

As shown in Table 1, while the yeast and mold growth on treated passion fruit surfaces was slower than in the control, microbial levels still increased during preservation. This phenomenon suggests that the antimicrobial effectiveness of chitosan needs to be enhanced, for example by incorporating silver nanoparticles, for better fruit protection.

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3.4 Effect of silver nanoparticle concentration on total yeast and mold

Table 2 demonstrates the decrease in yeast and mold growth on the surface of the passion fruits treated with a chitosan coating containing silver nanoparticles during storage. Specifically, the control sample exhibited a rapid increase in yeast and mold density, reaching 3.2 × 10^5 CFU/g after 10 days and 1 × 10^7 CFU/g after 20 days of storage. In contrast, silver nanoparticles in the chitosan coating significantly inhibited the growth rate of yeast and mold in the treated samples, extending their storage life by 5 to 7 days compared with the control. Data from Table 2 indicate that the yeast and mold count in the samples treated with silver nanoparticles after 20 days of storage were comparable with those observed in the control sample after only 15 days (as shown in Table 1). These results demonstrate that incorporating silver nanoparticles into chitosan coating effectively enhances the preservation of passion fruits. Notably, the passion fruit samples treated with a 5 mg/L silver nanoparticle chitosan coating exhibited the most significant preservation effect.

Table 2. Effect of silver nanoparticle concentration on total yeast and mold counts

Silver nanoparticles concentration (mg/kg)	The total yeast mold (CFU/g)				
	Day 0	Day 5	Day 10	Day 15	Day 20
0	ND(*)	6.5_x10^1	3.2_x10^5	8.3_x10^6	1.0_x10^7
1	ND	3.2_x10^1	2.4_x10^3	2.9_x10^5	7.9_x10^6
3	ND	2.9_x10^1	9.9_x10^2	2.1_x10^5	5.4_x10^5
5	ND	2.4_x10^1	9.5_x10^2	9.7_x10^4	1.3_x10^5

*ND: Not detected

The antimicrobial activity of silver nanoparticles can be attributed to the positive charge on their surface. This positive charge facilitates an electrostatic attraction between the silver nanoparticles and the negatively charged cell membranes of microorganisms. Specifically, the presence of thiol (–SH), carboxyl (–COOH), phosphate (PO_4^{3-}), and amine groups on the microbial cell membrane contributes to its negative charge. This interaction promotes the attachment of silver nanoparticles to the bacterial cell membrane, leading to the leakage of cellular components and subsequent cell death [15].

As illustrated in Fig. 6, the passion fruits preserved with a chitosan solution containing 5 mg/L of silver nanoparticles maintained their colour and glossiness and remained largely undamaged after 20 days of storage. The inclusion of silver nanoparticles enhances microbial inhibition efficiency, a finding consistent with studies on the preservation of dragon fruits [16] and green tomatoes [17] using coatings of chitosan-silver nanoparticles and chitosan-silicon nanoparticles, respectively. The results also demonstrated a significant increase in the antimicrobial efficacy of the chitosan coating when nano-sized particles were incorporated.

Fig. 6. Morphological changes of passion fruit peel samples dipped in 1% chitosan solution containing silver nanoparticles with different concentrations during 20 days of storage

3.5 Silver residue on passion fruit after 20 days of storage

A primary concern regarding the use of metal nanoparticles, particularly silver nanoparticles, in food preservation is the potential for residue on the product. Therefore, we analyzed silver residue in the fruit flesh of the passion fruits after film coating treatment. Interestingly, the results indicated that no silver residue was detected in experimental fruits, with a method detection limit (MDL) of 0.2 mg/kg (Table 3).

Table 3. Silver residue on passion fruit flesh after 20 days of storage

Sample	Testing criteria	Unit	Result	Method
CTS 1% + 1 mg/kg CTS 1% + 3 mg/kg CTS 1% + 5 mg/kg	Ag	mg/kg	Not dectected MDL = 0,2	CASE.TN.0131 (2020) (Ref. EPA 200.7)

4 Conclusion

This work successfully demonstrated the efficacy of a chitosan coating incorporating silver nanoparticles in extending the post-harvest shelf-life of passion fruits. The appropriate chitosan concentration to reach a well-preserved efficiency was found at 1%. Notably, incorporating silver nanoparticles significantly enhanced the antimicrobial activity of chitosan coating. The chitosan coating supplemented with 5 mg/L silver nanoparticles achieved the most promising results, extending the preservation time to 20 days at 25 ± 2 °C with minimal weight loss (~17.4%) and the lowest total yeast and mold count (1.3×10^5 CFU/g). Furthermore, the quality attributes of the fruits, including total soluble solids (14.83 $°B_x$), titratable acidity (6.59%), and vitamin C content in fruit flesh (18.41 mg/100 g), were maintained over the storage period. More impressively, no silver residue was detected in the fruit flesh after 20 days of storage. Consequently, these findings strongly suggest that the biodegradable chitosan-silver nanoparticle coating, with its excellent fruit quality maintenance features, represents a promising and safe solution to enhancing the post-harvest preservation of passion fruits, offering a potential alternative to conventional methods.

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