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Effect of Immersion Time and Packaging Type on the Quality of Curly Red Chili Coated with Chitosan–*Aloe vera*

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ABSTRACT

Curly red chili has a short shelf life such that post-harvest handling techniques, including edible coatings, are essential. This study aimed to determine the effect of edible coating immersion time and packaging type on the shelf life of curly red chili. The experiment used a completely randomized design (CRD) with two factors: immersion duration (5, 7.5, and 10 minutes) and polypropylene (PP) plastic packaging type (non-perforated and perforated). Data were analyzed using a Two-Way ANOVA, followed by Duncan's Range Multiple Test (DMRT) at a 95% confidence level. The parameters measured included weight loss, moisture content, vitamin C content, and respiration rate. The optimal treatment was A1B2 (5-minute immersion with perforated PP packaging), which achieved the highest vitamin C content (460.32 mg/100g), the lowest respiration rate (1.89 mg $CO_2.kg^{-1}.h^{-1}$), a weight loss of 26.82%, and a moisture content of 67.73%. Although weight loss in A1B2 was higher than in non-perforated packaging treatments, vitamin C and respiration rate were prioritized as key nutritional and metabolic quality indicators. Compared to control in perforated packaging (A0B2), treatment A1B2 yielded 24.60% higher vitamin C retention, demonstrating the added value of the chitosan–Aloe vera coating.

1. INTRODUCTION

Curly Red chili (*Capsicum annum* L.) is a staple agricultural commodity in Indonesia and is widely used as a culinary seasoning. It is nutritionally valuable and contains essential macronutrients such as carbohydrates, proteins, and fats as well as micronutrients such as calcium and vitamins A, B1, and C (Bal *et al*., 2022). Furthermore, it contains bioactive compounds, such as lasparaginase, which is known for its anticancer properties (Ambreen *et al*., 2019). According to the Badan Pusat Statistik (BPS, 2023), Indonesia's curly chili production reached 1.16 million tons in 2023, reflecting a 13.73% increase (or 140,000 tons) from the previous year. Despite its high production, curly red chili is a non-climacteric fruit with a short postharvest life. Its high respiration activity after harvest accelerates moisture loss, metabolic degradation, and quality deterioration. As a result, the freshness, texture, and nutritional quality of curly red chili rapidly decline during storage and distribution. Noted, chilies typically maintain quality for only 14 days at chilled temperatures, beginning to decline after day 7. This short shelf life aligns with the earlier recommendation of that packaged chilies should be stored for no more than one week. Curly red chilies can have a damage rate of up to 40%, primarily because of their high water content of 55–85% at harvest. According to Wigati *et al*. (2021), harvested red chilies continue to undergo respiration and transpiration, which leads to wilting. Therefore, proper post-harvest handling is essential to minimize damage and increase the added value of the product.

Edible coatings form a barrier that inhibits the release of gases and water vapor, while preventing direct contact with oxygen. This reduces the respiration rate and slows down the decay process. Consequently, edible coatings are expected to extend shelf life and maintain the quality of red chilies stored at room temperature (Krishnan *et al*., 2025). Edible

coatings can be formulated from materials such as hydrocolloids, lipids, and composites (Shufa *et al*., 2025). Polysaccharides such as cellulose and chitosan are widely used for this purpose (Wang *et al*., 2023).

Chitosan is an effective edible coating owing to its inherent antibacterial activity (Kumar *et al*., 2020). This activity originates from its positively charged amine groups, a feature that distinguishes it from the generally neutral or negative charges of other polysaccharides (Prieto-Santiago *et al*., 2025). Despite this antimicrobial advantage, its main limitation is its high water vapor permeability, making it a poor water barrier (Aziz *et al*., 2025). To address this limitation, *Aloe vera* gel can be incorporated as a synergistic complementary agent. The combination creates a composite coating system where chitosan provides the antimicrobial scaffold while *Aloe vera*'s hygroscopic polysaccharides (cellulose, glucomannan) and lipid components (triglycerides, sterols) enhance the moisture barrier and biological protection. Specifically, acemannan in *Aloe vera* reinforces the coating matrix, while saponins contribute additional antimicrobial activity. This synergistic mechanism results in a composite coating with superior moisture retention and antimicrobial properties compared to either component alone (Prieto-Santiago *et al*., 2025).

To overcome the water barrier limitations of chitosan, *Aloe vera* gel can be used as a complementary agent. Its hygroscopic character helps reduce moisture loss and regulates respiration in produce (Flores-López *et al*., 2024). The efficacy of *A. vera* stems from its complex composition, which includes polysaccharides such as cellulose and glucomannan, lipids such as triglycerides, and other bioactive compounds such as saponins and acemannan (Mensah *et al*., 2025). These components collectively form a protective coating and exhibit antimicrobial, antiviral, and tissue-repairing activities, which are advantageous for postharvest applications (Catalano *et al*., 2024).

Febriyanti (2020) identified a 2% chitosan and 10% *Aloe vera* formulation as the most effective edible coating for preserving the post-harvest quality of red chili peppers. A key limitation of this treatment, however, is the uneven application and poor adhesion of the coating. Therefore, optimizing the immersion time is a logical next step in this research. A longer or controlled immersion period may enhance the uniformity, as the duration of dipping is a known factor that influences the quality and evenness of edible coatings (Christina, 2017). The optimal immersion time for edible coatings appears to be formulation dependent. For instance, Perkasa *et al*. (2021) reported the best dipping time of 10.52 minutes for chitosan coating on red chilies. Conversely, a 5-minute immersion was optimal for *Aloe vera*-based coatings on other produce, such as strawberries with savory essential oil (Hassani *et al*., 2025) and fresh-cut melons with carboxymethyl cellulose and citric acid (Nasution *et al*., 2023).

The selection of packaging tailored to specific food characteristics is an effective strategy for preserving food quality. Suitable packaging prevents physical damage and pest infestation, and extends shelf life (Marotta *et al*., 2025). Research has indicated that polypropylene (PP) plastic is a superior packaging material for red chilies. Setiawan (2019) determined that 8-hole perforated PP packaging was optimal for large red chilies (*Capsicum annuum* L.). Similarly, Lamona *et al*. (2015) found that a non-perforated PP film was best for curly red chilies, highlighting the efficacy of the material while leaving the question of optimal perforation open for further study.

Previous studies have investigated chitosan or *Aloe vera* coatings separately; however, limited research has evaluated their combined application with optimized immersion time and packaging interaction, particularly for curly red chili under ambient storage. This study therefore hypothesizes that: (1) immersion time will significantly affect the uniformity and protective performance of the composite coating; (2) packaging type (perforated vs. non-perforated) will significantly affect water vapor exchange and gas atmosphere around the stored chili; and (3) there will be an interaction between immersion time and packaging type that affects postharvest quality parameters. The objectives of this study are: (1) to determine the optimal immersion duration (5, 7.5, or 10 minutes) for the application of a composite 2% chitosan–10% *Aloe vera* edible coating on curly red chili; (2) to compare the effect of perforated versus non-perforated PP packaging on postharvest quality; and (3) to identify the interaction between these two factors in determining overall quality retention during 15 days of ambient storage.

2. MATERIALS AND METHODS

2.1. Materials and Equipment

The materials used in this study consisted of curly red chilies obtained from a traditional market in Bogor. Chilies were selected based on uniform physical characteristics: length 10–15 cm, diameter 0.8–1.5 cm, weight 5–10 g per fruit,

bright red color indicating full commercial ripeness, firm texture, and freedom from physical damage, decay, pest infestation, or fungal contamination. Chitosan and fresh *Aloe vera* were used as the edible coating materials, prepared with distilled water and 1% (v/v) acetic acid as solvents. Polypropylene (PP) plastic in both perforated and non-perforated forms was used for packaging. Non-perforated PP bags measured 20 cm × 30 cm with a thickness of 0.03 mm. Perforated PP bags had the same dimensions with circular perforations of 5 mm diameter arranged in a uniform pattern of 8 holes distributed symmetrically on both faces of the bag. Analytical reagents included iodine, phenolphthalein (PP) indicators, starch, HCl, and NaOH. Equipment included a blender, magnetic stirrer with hot plate, analytical balance, oven, desiccator, Erlenmeyer flasks, burettes, pipettes, and measuring flasks.

2.2. Preparation of the Edible Coating Solution

2.1.1. Preparation of the Chitosan Solution

Chitosan solution was prepared according to the method of Mukdisari (2015). Chitosan powder (food/pharmaceutical grade, 200 mesh, derived from shrimp shells; CV. Sentra Teknosains Indonesia, Yogyakarta) was dissolved in 1% (v/v) acetic acid. A total of 10 g of chitosan powder was dissolved in 500 mL of 1% (v/v) acetic acid solution. The mixture was heated to 50°C and stirred for 60 min on a magnetic stirrer hot plate until a homogeneous, viscous solution formed, then filtered to remove impurities.

2.1.2. Preparation of *Aloe vera* Gel and Edible Coating Solution

Aloe vera gel was prepared following the method described by Febriyanti (2020) with modifications. Fresh *Aloe vera* leaves were cleaned with distilled water and the outer skin was carefully removed to isolate the inner parenchyma. The parenchyma was sliced, blended into a homogeneous paste, and filtered to obtain a pure gel. This gel was pasteurized at 75°C for 15 min, cooled to room temperature, and defined as 100% *Aloe vera* gel for subsequent use.

The chitosan and *Aloe vera* gel solutions were combined in a ratio of 2% chitosan to 10% *Aloe vera* gel following the optimal formulation identified by Febriyanti (2020). The mixture was homogenized using a magnetic stirrer for 5 min to get the solution ready for use.

2.3. Experimental Design

This study employed a factorial Completely Randomized Design (CRD). Factor I was immersion time (A) with three levels: 5 min (A1), 7.5 min (A2), and 10 min (A3). Factor II was packaging type: non-perforated PP plastic (B1) and perforated PP plastic (B2). Six treatment combinations was replicated 3 times. An additional uncoated control was included in both packaging types (C-B1 and C-B2), each replicated 3 times. A total of 24 experimental units were performed independently, consisting of a separate batch of chili samples (approximately 200 g per unit) coated, and packaged independently. Control treatments were included in the two-way ANOVA as a covariate reference to assess the added value of the coating treatment; however, the formal factorial analysis was performed on the 6 treatment combinations only (A1–A3 × B1–B2).

Chili samples were dipped in the coating solution for the assigned duration, allowed to drain and air-dry for 10 min, and then packaged. All samples were stored at ambient room temperature of 28–30 °C and relative humidity of 70–80% for 15 days. Quality parameters were measured at the end of the storage period (day 15).

2.4. Analysis of Coating Treatment Effects

The efficacy of the edible coatings was analyzed by measuring the key postharvest quality parameters. These include gravimetric weight loss (using a modified method from Cheng *et al*. (2023)), moisture content (AOAC, 1995), vitamin C content (Rukhana, 2017), and respiration rate (Rukhana, 2017).

2.4.1. Weight Loss

The gravimetric method was used to measure weight loss, as described by Cheng *et al*. (2023) with modifications. The initial weight of the chili was recorded before treatment and storage, and the final weight was recorded after the storage period. The percentage of weight loss was then calculated using the following formula:

$$Weight\ Loss\ (\%) = \left[\frac{(Initial\ Weight - Final\ Weight)}{Inital\ Weight}\right] \times 100\% \quad (1)$$

2.4.2. Moisture Content

The moisture content of the chili samples was determined in triplicate using the standard gravimetric method outlined by the AOAC (1995). A 5 g sample was placed in a pre-weighed and pre-dried aluminum cup. The sample was then heated in an oven at 105 °C for three hours, transferred to a desiccator to cool to room temperature, and subsequently weighed. This process of heating, cooling, and weighing was repeated until a constant weight was achieved, indicating that all moisture had been removed. The moisture content was calculated gravimetrically using the following formula:

$$Moisture\ Content\ (\%) = \left[\frac{(Initial\ Weight - Final\ Weight)}{Inital\ Weight}\right] \times 100\% \quad (2)$$

2.4.3. Vitamin C Concentration

The vitamin C content was determined in triplicate using a titration method based on Rukhana (2017). A 10-gram sample was homogenized with a mortar and pestle, transferred quantitatively to a 100 mL volumetric flask, and diluted to the mark with distilled water. The solution was then filtered. A 25 mL aliquot of the resulting filtrate was pipetted into an Erlenmeyer flask, and 2–3 drops of 1% starch solution were added as indicators. This mixture was titrated with a 0.01 N iodine solution until the endpoint was reached, as indicated by the appearance of a stable blue-black color. The vitamin C content was calculated based on the titer value, where 1 mL of 0.01 N iodine solution is equivalent to 0.88 mg of ascorbic acid, using the following formula:

$$Vitamin\ C\ (mg/100g) = \frac{(Titre\ Volume\ (mL) \times 0.88\ mg/mL \times Dilution\ Factor}{Sample\ weight\ (g)} \times 100 \quad (3)$$

2.4.4. Respiration Rate

The respiration rate was measured using a method modified from Rukhana (2017) based on the absorption of carbon dioxide (CO_2) evolved by the chili fruit. A sample of chilies was sealed in an Erlenmeyer flask connected to an air-circulation system. The Erlenmeyer flask used had a volume of 500 mL, containing approximately 200 g of chili sample. The incubation was conducted at ambient temperature (28–30 °C) and relative humidity of 70–80%. A vacuum pump was used to draw air from the headspace through a trapping flask containing a known volume of 0.1 N sodium hydroxide (NaOH) for one hour. The NaOH solution absorbed CO_2 to form sodium carbonate.

Following the one-hour incubation, a 10 mL aliquot of the NaOH solution was transferred to a new flask. Two drops of phenolphthalein (PP) indicator were added, and the solution was titrated with 0.1 N hydrochloric acid (HCl) until the pink color disappeared. This titration was used to determine the amount of unreacted NaOH. The respiration rate was calculated using the following formula, which quantifies the amount of CO_2 produced per kilogram of sample per hour:

$$Respiration\ Rate\ (mg/CO_2/\ kg\ /h) = \frac{[(V_b - V_s) \times N \times 22]}{(W \times T)} \quad (4)$$

where V_b is volume of HCl (mL) used to titrate the blank (NaOH without CO_2 exposure), V_s is volume of HCl (mL) used to titrate samples, N is normality of the HCl solution (0.1 N), 22 is the milliequivalent weight of CO_2 (mg/meq), W is weight of sample (kg), and T is incubation time (hours).

2.5. Data Analysis

Statistical analyses were performed using IBM SPSS Statistics, Version 25. The data were subjected to two-way ANOVA to evaluate the individual and interactive effects of immersion time and packaging type. When ANOVA indicated a significant difference ($p < 0.05$), post-hoc analysis was performed using Duncan's test to compare treatment means at a significance level of $\alpha = 0.05$.

3. RESULTS AND DISCUSSION

Curly red chili is a non-climacteric horticultural product with a high post-harvest moisture content and respiration rate (Widyastuti & Gahayu, 2022). After harvest, two key physiological processes drive quality degradation, namely transpiration and respiration. Transpiration, the loss of water vapor due to a pressure gradient between the fruit and its environment (Rossi *et al*., 2022), leads directly to weight loss, wilting, and loss of freshness (Maftoonazad & Ramaswamy, 2019). Concurrently, respiration breaks down complex compounds into simpler molecules, releasing energy, carbon dioxide, and water vapor. This process depletes vital nutrients such as vitamin C and accelerates senescence and decay (Ding *et al*., 2025). The combined effects of transpiration and respiration resulted in a progressive decline in quality during storage. Therefore, key post-harvest quality parameters for curly red chili include weight loss, moisture content, vitamin C content, and respiration rate.

3.1. Weight Loss

The quality of curly red chilies during storage can be assessed based on weight loss. As horticultural products, chili continue to respire and transpire post-harvest. Respiration consumes stored substrates, releasing gases and water vapor, while transpiration directly results in moisture loss. The combination of these processes leads to a measurable decrease in fruit mass (Maftoonazad & Ramaswamy, 2019). Figure 1 shows weight loss of chilies during 15 days of storage using two different packaging plastic. In both packaging plastics, control chilies (without edible coating) in general show higher weight loss compared to the coated chilies. This indicate that edible coating suppresses moisture evaporation from the chilies. The figure shows that weight loss of chilies stored using perforated plastic shows linear increase during storage, while unperforated plastic shows slightly fluctuating pattern. The figure also shows that cumulatively chilies stored using perforated plastic demonstrate much higher weight loss than that of unperforated one, implying important role of perforation in the postharvest handling for chilies.

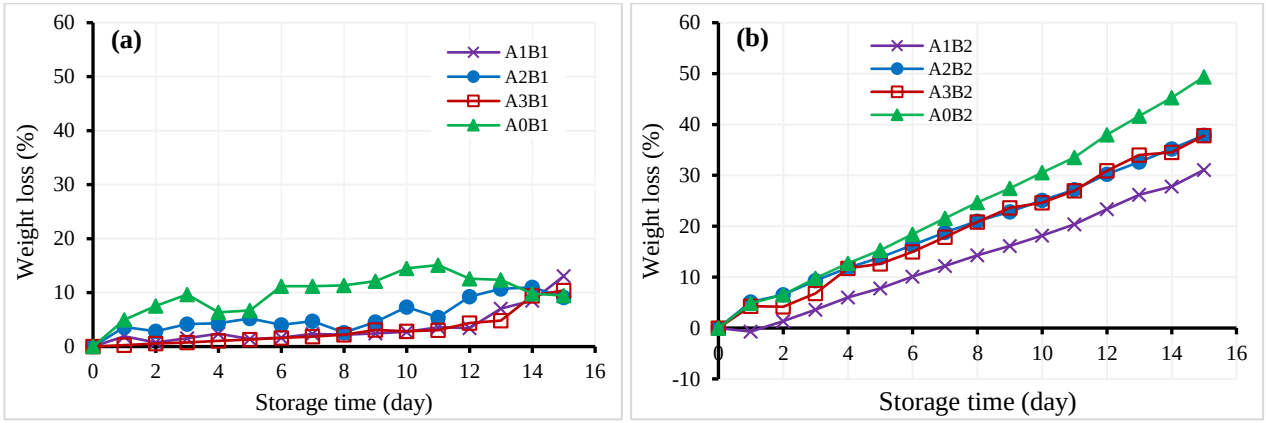

Figure 1. Development on weight loss of chili during storage for 15 days under different soaking durations and packaging types: (a) PP plastic without perforation, (b) PP plastic with perforation

Table 1. Effect of treatment on the percentage weight loss of chili samples on day 15

Immersion Time (A)	Weight loss (%)		Average (A)
	B1 (PP plastic no perforation)	B2 (PP plastic with perforation)	
A1 = 5 min	12.59±7.03	26.82±2.51	19.71±10.06^{x}
A2 = 7.5 min	9.27±4.84	31.96±6.58	20.61±16.04^{x}
A3 = 10 min	10.30±8.28	31.82±2.52	21.06±15.22^{x}
Average (B)	10.72±1.70^{p}	30.20±2.93^{q}	

Note: Means followed by same superscripts within same column and row are not significantly different according to DMRT at α = 0.05

Table 1 shows effect of treatment on the weight loss of curly red chilies during storage for 15 days. Results of ANOVA indicated that effect of immersion time and its interaction with packaging type is not significant with

significance values of $p = 0.92$ and $p = 0.41$, respectively. Packaging type alone, however, had a significant effect ($p = 0.00$) on the weight loss of chilies.

Duncan's test ($\alpha = 0.05$) revealed that perforated PP packaging (B2) resulted in significantly higher weight loss (30.20%) than non-perforated packaging (B1) with average weight loss of 10.72%. This difference is attributed to the higher water vapor transmission rate in the perforated packaging. The holes in B2 packaging allow water vapor produced from transpiration and respiration to escape more readily, lowering the relative humidity within the package. When the internal humidity is lower than the water potential of chilies, it creates a steeper vapor pressure gradient, accelerating moisture loss from the fruit tissue and leading to greater weight loss and potential wilting (Khoirunnisa *et al*., 2024). In contrast, the non-perforated packaging (B1) maintained a higher internal humidity by restricting air exchange, thereby slowing down the transpiration process and preserving weight.

The ANOVA results indicated that the immersion time had no significant effect on weight loss. Mean weight loss across all immersion times was statistically similar, ranging from 19.71% to 21.06%. These findings demonstrate that varying the immersion time of the edible coating is not an effective factor in controlling weight loss in curly red chilies. This non-significant immersion time effect on weight loss suggests that, within the 5–10 min range tested, the composite coating reached a functional plateau in moisture barrier performance. It is plausible that even a 5-min immersion was sufficient to deposit a continuous film over the chili surface, beyond which additional time did not enhance moisture retention. This observation has practical implications: shorter immersion time (5 min) can achieve equivalent moisture protection while reducing processing time and energy costs. The lack of statistical significance, however, does not preclude biologically meaningful trends, and future studies with larger sample sizes may have sufficient power to detect differences of practical importance.

A key trade-off is evident: while non-perforated packaging significantly reduced weight loss, it simultaneously created a high-humidity microclimate that, as discussed in Section 3.3, compromised vitamin C retention by promoting microbial activity. This trade-off between weight preservation and nutritional quality retention is a central finding of this study and must be considered when selecting the optimal treatment for practical application.

The progressive weight loss observed in curly red chilies during storage was attributed to two main factors: physiological processes and microbial activity. Physiological weight loss results from the continuous evaporation of water through transpiration and the catabolism of reserves during respiration (Maftoonazad & Ramaswamy, 2019). Additionally, microbial infestation can accelerate weight loss by breaking down cell walls and utilizing fruit carbohydrates, thereby leading to further tissue degradation (Rukhana, 2017). The weight loss observed in this study was higher than that reported by Febriyanti (2020). In the present study, the average weight loss of curly red chilies coated with 2% chitosan and 10% *Aloe vera* after 15 d of storage ranged from 3.25% to 5.08%. In contrast, Febriyanti (2020) used a thinwall box (typically made of 0.05 mm PP plastic), while this study employed a thinner, clear 0.03 mm PP plastic with 5 mm perforations (Setiawan, 2019). This discrepancy in results is likely attributable to the use of different packaging materials. Several factors influence the permeability of plastic packaging, including the thickness, atmospheric conditions (RH), temperature, and material composition. The thinner perforated plastic used in this study inherently offers less resistance to water vapor loss than the thicker non-perforated box, leading to the higher weight loss observed (Acerbi *et al*., 2016).

A comparison with Perkasa *et al*. (2021) revealed a lower rate of weight loss in this study. For a 5-minute immersion time, chitosan-coated chilies reached 16.6% weight loss by day 10. Conversely, the comparable treatment in this study (5-minute immersion in non-perforated PP packaging) showed only 12.59% weight loss after 15 days of storage. The interaction effect of packaging type and immersion time on weight loss was not statistically significant. Despite this, the main effect of packaging was evident, with non-perforated PP packaging maintaining lower weight loss across all immersion durations than perforated packaging.

The critical role of packaging was further demonstrated by the control treatments (A0), which lacked an edible coating. The control in non-perforated packaging (A0B1) exhibited minimal weight loss (9.43%), whereas the control in perforated packaging (A0B2) experienced severe weight loss (39.5%). This stark contrast aligns with the significant main effect of packaging identified by Duncan's test, indicating that non-perforated packaging (B1) is fundamentally more effective at reducing moisture loss than perforated packaging (B2), regardless of the coating application. The

significantly lower weight loss in the A0B1 control (non-perforated packaging) is due to restricted air exchange, which traps water vapor from transpiration and respiration. This creates a high-humidity microclimate inside the package, helping to maintain the moisture content of chili. This finding is consistent with that of Kertadana *et al*. (2020), who reported that non-perforated polypropylene packaging leads to water accumulation owing to its low water vapor permeability. As explained by (Chia & Lim, 2022), when the relative humidity (RH) of the surrounding air is higher than the water potential of the plant material, water vapor absorption can occur. In a sealed environment, this process can saturate the air and even lead to a net gain in the weight of the material, as moisture cannot escape.

3.2. Moisture Content

Moisture content is important to assess the post-storage quality of the curly red chilies. As horticultural products with a high initial moisture content, chilies are highly susceptible to quality degradation. This high moisture content drives postharvest transpiration and provides a medium for microbial growth, both of which accelerate spoilage (Fang & Wakisaka, 2021). Transpiration, the loss of water vapor due to a difference in vapor pressure between the fruit and its environment, directly leads to quality defects. Excessive water loss results in weight reduction, wilting, wrinkling, and loss of freshness (Maftoonazad & Ramaswamy, 2019). This process, coupled with respiration, causes a continuous decline in moisture content throughout storage. Both respiration and transpiration release water vapor, leading to a net loss of moisture from chilies to the surrounding atmosphere.

ANOVA results presented in Table 2 demonstrate a significant effect of packaging type ($p = 0.00$), but no significant effect for packaging type ($p = 0.34$) and the interaction of both factors ($p = 0.41$) on the weight loss of curly red chilies. Results of further DMRT at $\alpha = 0.05$ is presented in Table 2. Weight loss primarily occurs through moisture evaporation, the higher weight loss observed in perforated packaging (B2) logically corresponds to a lower final moisture content. Conversely, the non-perforated packaging (B1) preserved moisture by restricting water vapor loss, resulting in a higher retained water content. Perforated plastic regulate the exchange of water vapor, CO_2, and O_2.

Table 2. Effect of treatment on the water content of chili samples after 15 days

Immersion Time (A)	Packaging Type (B)		Average (A)
	B1 = PP plastic without perforations	B2 = PP plastic with perforations	
A1 = 5 minutes	78.93±1.51	67.73±1.14	73.33±7.92^{x}
A2 = 7.5 minutes	87.06±9.05	58.72±3.71	72.89±20.04^{x}
A3 = 10 minutes	84.46±5.10	52.34±13.42	68.44±22.65^{x}
Average (B)	83.48±4.15^{p}	59.63±7.69^{q}	

Note: Means followed by same superscripts within column or row are not significantly different according to DMRT at $\alpha = 0.05$

This interaction suggests that immersion time modulates moisture retention differently depending on packaging environment. In non-perforated packaging, a longer immersion may allow the coating to alter the chili epidermis, increasing absorption of trapped water vapor. In perforated packaging, longer immersion may progressively damage the cuticle, accelerating moisture loss through an already vapor-permeable environment. This physiological mechanism explains why the interaction reaches statistical significance despite the lack of significant main effect of immersion time. This prevents oxygen depletion and carbon dioxide accumulation inside the packaging. Without adequate ventilation, the lack of oxygen can cause respiration to become anaerobic, leading to the production of volatile compounds, such as alcohol and off-odors, which accelerate decay and quality degradation (Buthelezi& Mafeo, 2024).

Treatment using B2 packaging was proven to not cause rotting and undesirable aromas compared to treatment using B1 packaging, as can be seen in Appendix 5. However, the water content in B2 packaging is lower than that in the treatment using B1 packaging because packaging without perforation holes (B1) can accumulate water vapor in the packaging because the water in the packaging cannot escape to maintain the humidity of the chilies and their water content (Kertadana *et al*., 2020). The immersion time did not have a significant effect on the moisture content. The mean moisture content across all immersion times was similar, ranging from 68.44% to 73.33%. Specifically, the 5-minute, 7.5-minute, and 10-minute treatments resulted in average moisture contents of 73.33%, 72.89%, and 68.44%,

respectively. This demonstrates that varying the immersion time was not an effective factor for controlling the moisture content of chili.

The interaction between packaging type and immersion duration had a significant effect on the moisture content. Duncan's test (α = 0.05) revealed that the highest moisture content (87.05%) was achieved with 7.5-minute immersion in non-perforated packaging (A2B1), while the lowest (52.43%) was observed with 10-minute immersion in perforated packaging (A3B2). The results further indicated that non-perforated packaging (B1) was more effective in preserving moisture when combined with longer immersion times (A2 and A3). In contrast, perforated packaging (B2) resulted in a higher moisture retention when paired with the shortest immersion time (A1). This interaction can be explained by the competing effects of the coating and packaging. A longer immersion time may damage the chili cuticle or lead to an overly thick coating that is prone to cracking, thereby increasing water loss, especially in a perforated package that offers little resistance to vapor escape (Rukhana, 2017). Conversely, shorter immersion in perforated packaging may form a more optimal breathable coating that mitigates water loss better than no coating.

The moisture content of chili peppers is inversely proportional to weight loss; lower weight loss during storage indicates higher moisture retention. This relationship is well established, as water loss constitutes the primary component of postharvest weight loss (Gidado *et al*., 2024). Consequently, excessive water loss directly leads to wilting and a significant increase in the overall weight loss (Lufu *et al*., 2020). In non-perforated packaging (B1), longer immersion times (A2 and A3) resulted in a higher moisture content. The sealed environment creates low water vapor permeability, trapping moisture released from the chilies and preventing their escape. Furthermore, a longer immersion might alter the chili epidermis, potentially increasing its susceptibility to absorbing this trapped water vapor, which could also contribute to higher moisture readings (Kertadana *et al*., 2020). Conversely, in perforated packaging (B2), the longest immersion time (A3) resulted in the lowest moisture content. Perforations allow water vapor from respiration and transpiration to escape, preventing accumulation. In this scenario, a longer immersion time is detrimental, as it may excessively damage the cuticle, accelerating moisture loss in an environment that cannot be retained. The moisture content of the uncoated control chilies further demonstrated the significant effect of packaging. After 15 days, the control in non-perforated packaging (A0B1) retained 87.83% moisture, which was significantly higher than that in perforated packaging (A0B2) (62.2 %). This result directly aligns with Duncan's test for the packaging factor, confirming that non-perforated packaging (B1) is superior at preserving moisture compared with perforated packaging (B2).

3.3. Vitamin C Content

Measurement of vitamin C (ascorbic acid) content serves as an indicator of quality degradation in fruit and vegetable products during storage (Giannakourou & Taoukis, 2021). Although they are rich in vitamin C, chili experience a significant decline in vitamin C concentration over time. This is primarily due to the oxidation of ascorbic acid, which is intensified by exposure to air and elevated storage temperatures (Basak *et al*., 2023). Post-hoc analysis with Duncan's test confirmed that perforated packaging (B2) maintained a significantly higher vitamin C level (436.88 mg/100 g) than non-perforated packaging (B1), which averaged 223.72 mg/100 g.

This finding reveals a fundamental trade-off in postharvest management: non-perforated packaging preserved moisture and reduced weight loss, but simultaneously created a high-humidity microclimate that promoted microbial activity, which degraded vitamin C. Perforated packaging, while allowing greater moisture and weight loss, maintained lower humidity and suppressed microbial growth, thereby protecting vitamin C. This trade-off between physical quality (weight, moisture) and nutritional quality (vitamin C) is the most significant practical finding of this study. Treatment

Table 3. Effect of treatment on the vitamin C concentration (mg/100g) of chili samples after 15 days

Immersion Time (A)	Packaging Type (B)		Average (A)
	B1 = PP plastic without perforations	B2 = PP plastic with perforations	
A1 = 5 minutes	279.74±33.92	460.32±55.19	370.03±127.69^{x}
A2 = 7.5 minutes	166.05±86.05	424.00±284.98	295.02±182.40^{x}
A3 = 10 minutes	225.35±61.35	426.34±117.67	325.85±142.12^{x}
Average (B)	223.72±56.86^{p}	436.88±20.33^{q}	

Note: Means followed by same superscripts within column and row are not significantly different according to DMRT at α = 0.05

with perforated packaging (B2) resulted in higher vitamin C retention, despite higher weight loss and lower moisture content. This finding appears to contradict the general principle that vitamin C degrades with moisture loss. However, the high-humidity environment in the non-perforated packaging (B1), while reducing water loss, likely created conditions favorable for microbial growth. As microorganisms proliferate, they consume nutrients, including organic acids, such as ascorbic acid (Vitamin C), thereby accelerating their degradation (Rukhana, 2017). Therefore, perforated packaging, by maintaining a less humid atmosphere, may have indirectly preserved vitamin C by suppressing microbial activity that leads to its rapid breakdown. Edible coatings, comprising chitosan and *Aloe vera* gel, possess inherent antimicrobial properties (Kaur *et al*., 2024). However, the high-humidity microclimate created by nonperforated packaging can promote microbial growth to a level that may overwhelm the protective capabilities of the coating. Consequently, the risk of spoilage can be higher in non-perforated packaging, even with the coating, than in a more ventilated, perforated package. According to Anggraini & Permatasari (2017), effective packaging for fresh produce must have a high gas permeability and a design that inhibits wilting and transpiration. The inclusion of perforations is a key feature to meet these requirements, as it prevents the buildup of CO_2 and depletion of O_2 that leads to anaerobic respiration, decay, and off-odors (Asgar, 2017).

ANOVA results in Table 3 indicated that there is a significant effect of packaging type ($p = 0.035$), but no significant effect for packaging type ($p = 0.754$) and the interaction of both factors ($p = 0.917$) on the weight loss of curly red chilies. Duncan's test ($\alpha = 0.05$) revealed significant differences between the two packaging types on vitamin C concentration. The mean values across different soaking durations ranged from 295.0 to 370.0 mg/100 g. This demonstrates that the manipulation of the soaking time was not an effective treatment for determining the final vitamin C content. Although the interaction between packaging type and immersion time was not statistically significant, the type of packaging had a clear effect on vitamin C content. Regardless of the immersion duration, samples in non-perforated PP packaging consistently showed lower vitamin C levels than those in perforated PP packaging. The vitamin C content of the control chili (without coating) was assessed across the two packaging types. After a 15-day storage period, the sample in non-perforated PP packaging (A0B1) contained 149.7 mg/100 g of vitamin C, whereas the sample in perforated packaging (A0B2) contained 369.7 mg/100 g. This demonstrates that non-perforated packaging (B1) was associated with significantly lower vitamin C retention. Duncan's post hoc test on the packaging factor independently confirmed this finding, showing a statistically significant difference between the two packaging types. The susceptibility of vitamin C to oxidation can be addressed through post-harvest treatments such as edible coatings. These coatings form a semi-permeable layer that reduces oxygen contact and inhibits the escape of water vapor and gases. As noted by Dai *et al*. (2025), this suppression of gas exchange lowers the respiration rate, delays ripening, and slows overall metabolic activity, all of which help to preserve vitamin C content of chilies.

The primary mechanism by which edible coatings preserve vitamin C is by suppressing oxygen ingress, thereby preventing oxidative degradation (Rukhana, 2017). This barrier function is a key characteristic of an effective coating. For example, chitosan creates a particularly effective barrier against moisture and oxygen (Vírseda *et al*., 2025). In addition to simple barrier properties, coatings such as *Aloe vera* gel offer active protection. Its functional components, including carbohydrates, lipids, and antimicrobial agents such as glucomannan, saponin, and acemannan, further inhibit microbial damage and spoilage in chili (Destiana *et al*., 2021; Mensah *et al*., 2025). The quality of red chilies is positively correlated with ascorbic acid (Vitamin C) content (Ramadhanu *et al*., 2025). The literature indicates that the concentration of vitamin C (ascorbic acid) in chili, expressed on a dry weight basis, ranges from 221.25 to 327.29 mg per 100 g (Jayan *et al*., 2025). An outlier is the study by Legowo & Ajis (2020), which documented a much higher value of 571.6 mg/100 g. In this study, following a 15-day storage period, the measured vitamin C levels for all treatments were 166.05–460.32 mg/100 g. As expected after storage, these results are lower than the high baseline set by Legowo & Ajis (2020) but provide a realistic assessment of vitamin C retention under experimental conditions. Water loss during storage, especially at room temperature, leads to the diffusion of water-soluble vitamins, such as vitamin C, from chili tissue. This is compounded by the inherent instability; which is easily oxidized by air, degraded by heat, and can break down during fruit ripening process (Giannakourou & Taoukis, 2021). Therefore, the higher values in this study suggest that specific coating or storage conditions may be more effective in mitigating these forms of degradation.

Although these differences did not reach statistical significance, the consistently lower vitamin C in 7.5-minute treatments compared to 5- and 10-minute treatments across packaging types may reflect a non-linear relationship between immersion time and coating quality. A medium immersion duration may result in a coating layer with suboptimal structural integrity, though this hypothesis requires further investigation with targeted experiments.

3.4. Respiration Rate

Respiration rate was measured post-storage to assess the metabolic activity of the horticultural products. This measurement is a critical determinant of shelf life because an elevated respiration rate accelerates metabolic processes and leads to a shorter postharvest life (Lamona *et al*., 2015). This relationship is well established, with Rukhana (2017) noting that a high respiration rate typically correlates with short shelf life. Key factors that modulate the respiration rate include the ambient temperature and permeability of the skin of the fruit.

ANOVA results in Table 4 indicated that no treatment factor is significant with $p = 0.58$ for the immersion time, $p = 0.35$ for packaging type, and $p = 0.28$ for the interaction of the immersion time and the packaging type. The average rates were 2.20 mg $CO_2 \cdot kg^{-1} \cdot h^{-1}$ for non-perforated packaging (B1) and 2.08 mg $CO_2 \cdot kg^{-1} \cdot h^{-1}$ for perforated packaging (B2). The mean rates for 5-minute (A1), 7.5-minute (A2), and 10-minute (A3) immersions were 2.076, 2.207, and 2.127 mg $CO_2 \cdot kg^{-1} \cdot h^{-1}$, respectively. Data from the control treatments (without edible coating) provide further insight: the respiration rate was 2.08 mg $CO_2 \cdot kg^{-1} \cdot h^{-1}$ in non-perforated packaging (A0B1) compared to 1.59 mg $CO_2 \cdot kg^{-1} \cdot h^{-1}$ in perforated packaging (A0B2).

Table 4. Respiratory activity (mg $CO_2 \cdot kg^{-1} \cdot h^{-1}$) after 15 days

Immersion Time (A)	Packaging Type (B)		Average (A)
	B1 = PP plastic without perforations	B2 = PP plastic with perforations	
A1 = 5 minutes	2.27±0.15	1.89±0.34	2.08±0.27
A2 = 7.5 minutes	2.20±0.28	2.21±0.13	2.21±0.01
A3 = 10 minutes	2.12±0.00	2.13±0.25	2.13±0.01
Average (B)	2.20±0.08	2.08±0.17	

Although the statistical interaction was not significant, this consistent difference between packaging types across all treatments indicated that packaging perforation was a more influential factor on respiration rate than immersion time. A consistent numerical trend is observed: perforated packaging consistently yielded lower or comparable respiration rates compared to non-perforated packaging within each immersion time level. In the control group, this difference was more pronounced (A0B2: 1.59 vs. A0B1: 2.08 mg $CO_2 \cdot kg^{-1} \cdot h^{-1}$), suggesting that packaging perforation may have a biologically meaningful effect on respiration suppression that the current study lacked statistical power to detect. The low coefficient of variation and relatively small sample size may limit test sensitivity. Future studies with larger sample sizes or replications are recommended to clarify this relationship.

The elevated respiration rate in the non-perforated packaging can be explained by the accumulation of respiratory heat within the sealed package (Lamona *et al*., 2015). Perforated packaging mitigates this problem by facilitating gas exchange. According to Anggraini & Permatasari (2017), perforations help to maintain optimal levels of O_2, CO_2, and water vapor, which slows quality degradation. This principle is supported by Asgar (2017), that while plastic bags can suppress respiration, they must be perforated to avoid anaerobic reactions that cause spoilage and off-odors.

4. CONCLUSION

This study investigated the effects of immersion time (5, 7.5, 10 minutes) and packaging type (perforated vs. non-perforated PP) on the postharvest quality of curly red chili coated using chitosan–*Aloe vera* and stored at ambient temperature (28–30°C, RH 70–80%) for 15 days. Packaging type was the dominant factor, significantly affecting weight loss, moisture content, and vitamin C retention. Immersion time had no significant main effect on any parameter; however, a significant interaction between immersion time and packaging type was observed for moisture content, suggesting that coating duration modulates moisture dynamics differently depending on the barrier properties of the packaging material. The optimal treatment was A1B2 (5-minute immersion with perforated PP packaging), which achieved the highest vitamin C retention (460.32 mg/100g, 24.6% higher than the uncoated control in perforated packaging), the lowest respiration rate (1.88 mg CO_2/kg/h), with a weight loss of 26.82% and moisture content of 67.73%. While this treatment resulted in higher weight loss than non-perforated packaging, vitamin C and respiration rate were prioritized as nutritional and metabolic quality determinants in selecting the best treatment. For postharvest

scenarios where weight loss is the primary commercial concern, non-perforated packaging may be considered, though this entails a significant compromise in vitamin C retention.

For practical application, PP perforated packaging is recommended for retail and export markets where nutritional quality, freshness, and absence of off-odors are prioritized. Future research should: (1) evaluate additional quality parameters including color, firmness, and microbial load to provide a more comprehensive quality profile; (2) assess the economic feasibility of chitosan–*Aloe vera* coating at commercial scale; (3) investigate the efficacy of the composite coating under refrigerated conditions to extend shelf life; and (4) conduct studies with larger sample sizes to enhance statistical power for detecting treatment effects on respiration rate.

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AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
MR	✓	✓	✓	✓					✓	✓		✓	✓	✓
SZT					✓	✓	✓	✓	✓					
TF	✓	✓								✓	✓	✓	✓	

C: Conceptualization
M: Methodology
So: Software
Va: Validation
Fo: Formal Analysis
I: Investigation
D: Data Curation
R: Resources
O: Writing - Original Draft
E: Writing - Review & Editing
Vi: Visualization
Su: Supervision
Fu: Funding Acquisition
P: Project Administration

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