*J. Food Sci. Gastron.* (July - December 2025) 3(2): 1-9
https://doi.org/10.5281/zenodo.16741097
ISSN 3073-1283

JFSG
JOURNAL OF FOOD SCIENCE AND GASTRONOMY

ORIGINAL ARTICLE

# Biodegradable chitosan salt coatings as a sustainable strategy for the preservation of fresh tomatoes (*Solanum lycopersicum* L.)

## Coberturas biodegradables de sales de quitosana como estrategia sostenible para la conservación de tomates (*Solanum lycopersicum* L.) frescos

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Received: 04 April 2025 / Accepted: 02 July 2025 / Published online: 31 July 2025


**Abstract** The consumption of fresh fruits and vegetables, such as tomatoes, is associated with the prevention of chronic diseases; however, their shelf life is limited due to high perishability. This study aimed to evaluate the effect of biodegradable chitosan salt coatings (lactate and acetate) on the postharvest preservation of *Solanum lycopersicum* cv. Charleston tomatoes. Tomatoes harvested at the breaker stage were coated with 1.5% chitosan lactate and acetate solutions and stored at room temperature for 16 days. Physicochemical (pH, soluble solids, acidity, moisture, weight loss, and firmness) and physiological (ripening stage, wrinkling, and fungal damage) parameters were analyzed. The results showed that chitosan lactate coatings significantly delayed ripening, preserved firmness, and reduced visual deterioration. Chitosan acetate preserved acidity more effectively but showed greater dehydration. No significant differences were found in soluble solids or moisture content. Both coatings demonstrated antimicrobial properties. In conclusion, chitosan salt-based edible coatings, particularly the lactate form, offer a sustainable and effective strategy for extending the shelf life and maintaining the quality of fresh tomatoes.

**Keywords** fresh tomatoes, chitosan, edible coatings, postharvest preservation, ripening, biodegradability.

**Resumen** El consumo de frutas y hortalizas frescas, como el tomate, se ha relacionado con la prevención de enfermedades crónicas; sin embargo, su vida útil es limitada por su alta perecibilidad. Este estudio tuvo como objetivo evaluar el efecto de recubrimientos biodegradables de sales de quitosana (lactato y acetato) sobre la conservación postcosecha de tomates *Solanum lycopersicum* variedad Charleston. Se aplicaron soluciones al 1,5% de quitosana en ácido láctico y acético sobre frutos cosechados en estado de "pinta" y almacenados durante 16 días a temperatura ambiente. Se analizaron parámetros fisicoquímicos (pH, sólidos solubles, acidez, humedad, pérdida de peso y firmeza) y fisiológicos (estado de maduración, deterioro por arrugas y daño fúngico). Los resultados indicaron que el recubrimiento con quitosano lactato retardó significativamente la maduración, preservando la firmeza y reduciendo el deterioro visual, mientras que el acetato de quitosano fue eficaz en conservar la acidez, aunque presentó mayor deshidratación. No se observaron diferencias significativas en los sólidos solubles o contenido de humedad. Ambos tratamientos evidenciaron propiedades antimicrobianas. En conclusión, los recubrimientos de sales de quitosana, especialmente el lactato, representan una estrategia sostenible y eficaz para prolongar la vida útil del tomate fresco.

**Palabras clave** tomates frescos, quitosano, recubrimientos comestibles, conservación postcosecha, maduración, biodegradabilidad.

**How to cite**
García, Y. P., Morejón, B., Calderín, L., Fundora-Fernández, L., & Cordovés , A. (2025). Biodegradable chitosan salt coatings as a sustainable strategy for the preservation of fresh tomatoes (*Solanum lycopersicum* L.). *Journal of Food Science and Gastronomy*, *3*(2), 1-9. https://doi.org/10.5281/zenodo.16741097

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PUBLIS EDITORIAL

## Introduction

Adequate consumption of fruits and vegetables has been widely linked to the prevention of chronic non-communicable diseases, thanks to their high content of vitamins, minerals, fiber, and bioactive compounds. Several studies have indicated that a daily intake of at least 400 g of fruits and vegetables is associated with lower overall mortality and a reduced risk of cardiovascular disease, some types of cancer, type 2 diabetes, and respiratory diseases (Aune et al., 2017; Devirgiliis et al., 2024). Furthermore, there is evidence supporting their positive effect on mental health and psychological well-being (Boehm et al., 2021).

However, the consumption of fresh fruits and vegetables has been limited by changes in lifestyles, which demand convenient and quick-to-prepare foods. This has increased interest in minimally processed vegetables, which are fresh products that have been peeled, cut, or diced, thereby preserving their original nutritional, organoleptic, and functional properties (Champa & Weerasooriya, 2025). However, minimal processing leads to an acceleration of the product's metabolism, increasing the rate of respiration and ethylene production, which significantly reduces its shelf life, even under optimal storage conditions (Palumbo et al., 2022).

As a technological alternative to prolong the post-harvest life of fruits and vegetables, the use of edible films and coatings has been extensively studied (Díaz et al., 2010). These semipermeable barriers reduce water loss, regulate gas exchange, and can incorporate antimicrobial or antioxidant agents that delay product deterioration (Galus & Kadzińska, 2015; Chettri et al., 2023). In particular, chitosan, a polysaccharide derived from the deacetylation of chitin, is effective in forming biodegradable films with antifungal and antimicrobial properties (García, 2015), high barrier capacity, and good compatibility with other biopolymers (Hassan et al., 2018).

Chitosan can dissolve in weak acids, such as acetic or lactic, forming salts with similar film-forming properties. These solutions have been successfully used as edible coatings on fruits and vegetables, promoting the conservation of physicochemical parameters such as firmness, soluble solids content, pH, and titratable acidity (Chettri et al., 2023). In this context, the present study aimed to evaluate the effect of applying biodegradable chitosan salt coatings as a sustainable strategy for conserving fresh tomatoes (*Solanum lycopersicum* L.).

## Methodology

Tomatoes (*S. lycopersicum*) variety Charleston, grown under hydroponic conditions, were used. The fruits were harvested at the breaking stage (USDA, 1991) and selected based on uniform size, ripeness, and absence of visible defects. They were then divided into batches according to the established treatments.

Edible coatings were prepared from 1.5% (m/v) chitosan acetate and lactate solutions (de la Paz et al., 2024), made with 270 kDa chitosan and 75% deacetylation, supplied by the Center for Drug Research and Development (Havana, Cuba). The solutions were magnetically stirred for 30 min at room temperature using distilled water as a solvent.

The tomatoes were washed with potable water, disinfected with a sodium hypochlorite solution (80 mg/L), and then dried at room temperature and a relative humidity of 50%. The coatings were applied by immersion for one minute, followed by draining and drying on stainless steel racks with forced air flow (22 °C, 80% RH). The tomatoes were packaged in plastic baskets and stored at room temperature for 16 days.

Three treatments were established: a control batch (TC1, uncovered), a chitosan lactate treatment (TLQ), and a chitosan acetate treatment (TAQ). Physical-chemical quality assessments were performed at different storage intervals. Destructive analyses (moisture content, soluble solids, acidity, pH, and degree of penetration) were performed on days 0, 7, 10, 14, and 16; while the percentage of weight loss and ripeness were assessed on days 0, 4, 7, 9, 10, 14, and 16.

The soluble solids content was determined according to NC-ISO 2173 (2001), expressed in °Brix. The pH was measured using a potentiometer (NC-ISO 1842, 2001), and the titratable acidity was determined by a volumetric neutralization method (NC-ISO 750, 2001), expressed as a mass/mass percentage of the majority acid. The soluble solids/acidity ratio was multiplied by 10 to facilitate graphic interpretation. The moisture content was determined by indirect gravimetry on a Sartorius MA-40 thermogravimetric balance at 105 °C (NC 77-22-8, 1982).

Weight loss was calculated gravimetrically using a Sartorius BS2202S technical balance (accuracy 0.01 g) and expressed as a percentage of the initial weight. The degree of penetration was measured using a cone penetrometer (30°, 150 g) for 5 seconds in free fall (Bataller et al., 2010).

Tomato ripeness was assessed using a graphic scale adapted from Wills et al. (1998), and the results were expressed as the percentage of fruit per stage in each lot. Physiological deterioration was assessed visually at the end of storage, with tomatoes classified into four wrinkle levels (A1 to A4). Those with a wrinkle level of A3 or higher were considered severely deteriorated.

The determinations were performed in triplicate, except for those corresponding to the degree of penetration, weight loss, and maturity, which were specific to the tomato. The data were analyzed using factorial analysis of variance with the Statistica program. Statistical differences were evaluated using Duncan's multiple range test ($p \leq 0.05$).

## Results and discussion

Table 1 presents the main physicochemical parameters of the tomato. These analyses enable the proper characterization of the product and serve as a basis for comparison with other fruits or processed formulations.

**Table 1.** Characterization of fresh tomato (n=5)

| Parameters | Mean (standard deviation) |
|---|---|
| Mass (g) | 166 (29) |
| Soluble solids (°Brix) | 2.0 (0.0) |
| pH | 4.34 (0.01) |
| Humidity (% m/m) | 93.3 (0.3) |
| Penetration distance (1/10 mm) | 18.0 (1.0) |
| Acidity (% m/m citric acid) | 0.25 (0.01) |

The observed value of 2.0 °Brix is considerably lower than those reported in other studies where it increased with storage and reached between 4–7 °Brix (Venkatachalam et al., 2024) or approximately 16°Brix in cases of ripe tomatoes or treated with varying concentrations of chitosan (Sucaritha et al., 2018). This suggests that the tomatoes evaluated were at an earlier stage of maturity or experienced lower concentrations of soluble solids, possibly due to the coating formulation.

The pH of 4.34 and acidity of 0.25% reflect slightly more acidic products compared to typical values in ripe tomatoes, which typically have a pH between 4.3 and 4.7 and an acidity of between 0.35% and 0.40% citric acid (Sucharitha et al., 2018; Safari et al., 2020). The use of chitosan-lactic or acetic acid coatings can better preserve organic acids, thereby reducing the increase in pH during storage (Peralta-Ruiz et al., 2020).

A moisture content of 93.3% is consistent with reported figures of around 93–94% in fresh tomatoes (<95%) (Sucharitha et al., 2018). Although weight loss is not reported here, other studies have indicated that chitosan coatings can reduce moisture and mass loss by 4–8% compared to the control, depending on the chitosan concentration and storage conditions (Venkatachalam et al., 2024; Kibar et al., 2018).

Penetration was recorded at 18 (1/10 mm), equivalent to 1.8 mm. Comparable data in the literature show that firmness is better preserved in chitosan-coated fruits, with significantly lower penetrations compared to the control (i.e., higher strength) (Kibar et al., 2018; Adainoo et al., 2023). A penetration of 1.8 mm could indicate a moderately firm texture, although it is difficult to compare directly without measurements in Newtons or other standard units.

Overall, the results indicate tomatoes with low soluble solids and moderate acidity, high moisture content, and relative firmness. Studies such as Safari et al. (2020) reported that combined coatings of chitosan with vanillin better preserved acidity, pH restriction, and soluble solids stability for up to 25 days (Safari et al., 2020). Likewise, Peralta-Ruiz et al. (2020) observed that additions such as essential oils improve acidity conservation and moisture retention in tomato cv. "Chonto" during cold storage (Peralta-Ruiz et al., 2020). On the other hand, low soluble solids values could suggest lower initial physiological maturity or water oversaturation, which would limit the perceived flavor, although it favors greater firmness and shelf life.

The values presented reflect tomatoes with high moisture content and moderate firmness, preserved acidity, and low soluble solids. Compared with the literature, they appear to indicate an effective formulation in maintaining moisture and texture. However, they could benefit from additional strategies (such as combining with essential oils or adjusting chitosan concentration) to better preserve soluble solids and acidity during prolonged storage.

The state of ripeness is a crucial aspect to consider when harvesting, as the subsequent treatment and storage conditions will depend on it, as well as the product's physiological and nutritional state. Closely related to the state of ripeness is the evolution of color, and, in the case of tomatoes, it undergoes notable organoleptic changes during ripening, with a decrease in chlorophyll and an increase in lycopene, pigments that significantly contribute to the product's quality. As it ripens, the tomato fruit acquires a red color as a result of the replacement of degraded chlorophylls by carotenoid pigments, bringing with it an increase in lycopene, its specific and most abundant carotene, and in xanthophylls, when chloroplasts are converted into chromoplasts (Carrillo-López & Yahia, 2014).

Figure 1 illustrates the behavior of the state of maturity during storage for each of the treatments conducted. If we take into account that this variety of tomato is not long-lived. The marketing cycle is between 10 and 12 days in refrigeration at a temperature of 6-8 °C (García et al., 2014), it is observed that the two treatments delayed the degree of ripening concerning the pattern, the chitosan lactate treatment (TLQ) being the most effective, since it is the only treatment in which tomatoes are observed in a state of maturity (6) up to 16 days of storage. Regarding the treatment with chitosan acetate (TAQ), a greater delay was evident in the first days of storage, from day 10, it declined, showing a behavior similar to the pattern.

The delay in ripening in the TLQ treatment is a result of the barrier action of the coating, which prevents oxygen and other volatile gases, such as ethylene, from entering and causing ripening (Pen & Jiang, 2003). Total solids and soluble solids content are correlated indices; however, soluble solids content is typically used because it is easier to determine. It is the index that most influences the yield during the production of tomato derivatives.

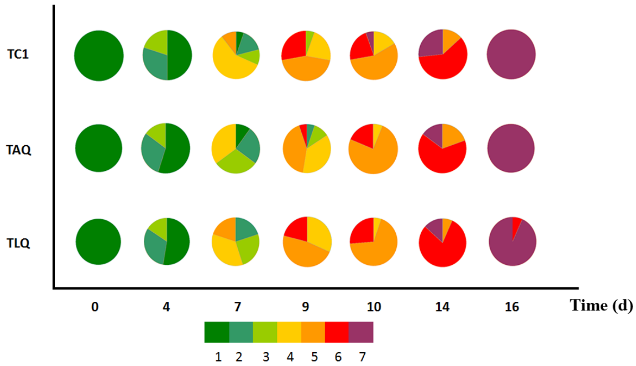


**Figure 1.** Classification of tomatoes according to ripeness during storage. TC1: control treatment; TAQ: chitosan acetate coating; and TLQ: chitosan lactate coating.

Sugars and organic acids are the main components of soluble solids. During ripening, the sugar content increases until it reaches a maximum and then generally remains constant. In contrast, the acid content decreases as a result of their dissolution and metabolism (Antala et al., 2025). During tomato ripening, the soluble solids content increases, but not significantly (Gross et al., 2003).

When analyzing Table 2, it can be observed that there is a tendency for the soluble solids content to increase during storage, without presenting significant differences between the treatments. The slight variation obtained is in agreement with findings reported by other authors (Cordenunsi et al., 2003; Pelayo et al., 2003). After the seventh day of storage, the soluble solids content stabilized.

**Table 2.** Behavior of soluble solids in tomatoes during storage

| Time (d) | Soluble solids (ºBrix ) | | |
|---|---|---|---|
| | TC1 | TAQ | TLQ |
| 4 | 2.0 (0.0) a | 2.0 (0.0) a | 2.0 (0.0) a |
| 7 | 2.5 (0.0) ab | 2.5 (0.0) ab | 2.0 (0.0) a |
| 9 | 3.0 (0.7) bc | 2.5 (0.0) ab | 3.0 (0.0) bc |
| 10 | 3.0 (0.0) bc | 2.5 (0.0) ab | 3.0 (0.0) bc |
| 15 | 3.3 (0.3) c | 2.5 (0.0) ab | 2.8 (0.3) bc |

Mean (standard deviation); n=3.

Different letters indicate significant difference ($p \leq 0.05$).

This occurs due to the consumption of sugars and organic acids during fruit respiration, the conversion of organic acids into sugars, and the loss of water due to dehydration, as well as the hydrolysis of polysaccharides, which releases soluble sugars, a typical process in the fruit's metabolism. This results in a negative balance of organic acids and a regulation of the sugar content, which translates into a stabilization of soluble solids (Antala et al., 2025).

The pH value is linked to the acid content present in the fruit. These two parameters show us the evolution of the ripening process during storage. As the tomato ripens, the acidity in the fruit decreases, and therefore the pH tends to increase.

Figure 2 shows a similar pattern of behavior for each treatment, with no significant differences between them. This corresponded to a decrease in the first 7 days of storage, followed by an increase over the following two weeks, as reported by García et al. (2014). This increase is associated with the decrease in citric acid content that occurs during fruit ripening.

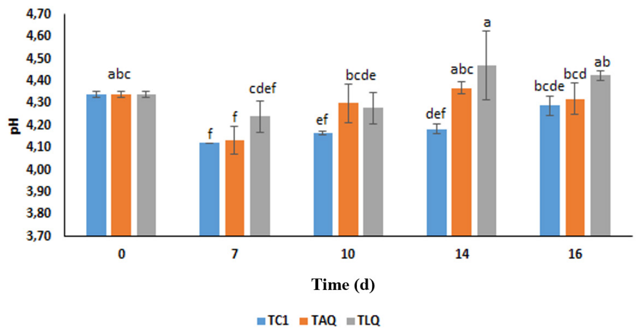


**Figure 2.** Behavior of pH during storage. Error bars indicate standard deviation (n=3). Different letters indicate a significant difference ($p \leq 0.05$).

The results of the ANOVA indicated that the pH did not change significantly ($p > 0.05$) during the storage period, although differences were observed between samples, attributed to sample variability rather than treatment, as no clear trends were associated with coating type. The pH values for the different treatments and storage times were approximately 4.1 and 4.5, similar to those reported by García et al. (2014) for tomatoes of the var. FA-180 treated with chitosan exhibited pH values between 4 and 4.4. Due to the nature of the fruit's organic acids, the normal decrease in its acidity did not cause noticeable changes in pH.

The acidity behavior (Figure 3) generally corresponds to the evolution of pH during storage. Statistical analysis of the results revealed significant differences ($p \leq 0.05$) in both storage time and treatments applied to the tomatoes, with the batch treated with acetate (TAQ) being the least acidic, despite presenting a higher state of ripeness, similar to that reported by García et al. (2014).

Acidity tends to increase until the 10th day of storage, after which it begins to decline. This behavior suggests that after reaching a maximum acid content, the conversion of organic acids into sugars begins, serving as a substrate in the respiration process. This is evident from the stability of the curve and the aging of the fruit. This is due to the climacteric nature of the fruit, which undergoes a rapid ripening process and then declines over time. Thus, the action of the TLQ treatment is evident, with a peak occurring at a longer storage time, which is related to a delay in the normal ripening process.

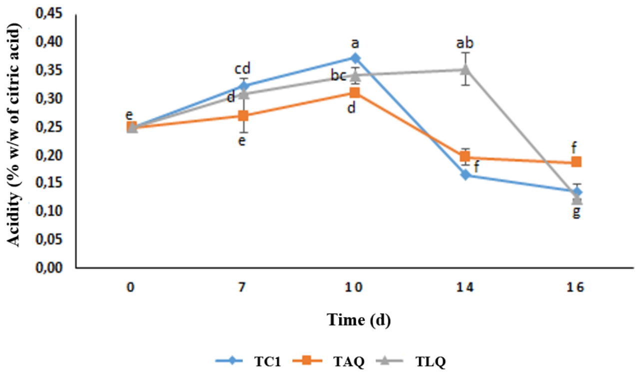


**Figure 3.** Acidity percentage behavior during storage. Error bars indicate standard deviation (n=3). Different letters indicate a significant difference ($p \leq 0.05$).

The percentage of soluble solids to percentage of acidity ratio (Figure 4) is considered an index of maturity for citrus fruits; however, in tomatoes, it is used as a flavor indicator. This relationship was primarily influenced by acidity, as the soluble solids values showed slight variation, a finding that aligns with previous reports by other authors (Bataller et al., 2010; García et al., 2014). Figure 4 shows an increase in the soluble solids/acidity ratio, or maturity index, after two weeks of storage, where it had remained constant until then. From this point on, the TAQ treatment proved to be the most effective, marking a notable difference from the other two treatments.

This occurs due to the lower respiration rate exhibited by the treated fruits compared to the control ones, since the increase in $CO_2$ is due to the use of reserve substrates in the Krebs cycle, which in the case of fruits are sugars and organic acids (Figueroa, 2011).

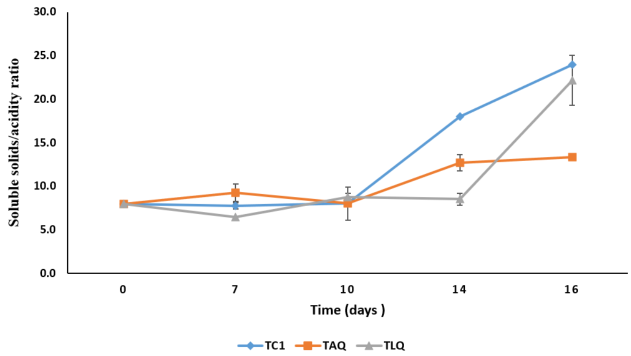


**Figure 4.** Behavior of the soluble solids percentage/acidity percentage relationship during storage. Error bars indicate standard deviation (n=3).

The TAQ treatment showed greater effectiveness in preserving quality parameters during tomato storage up to the first 10 days of storage, as evidenced by color, pH, soluble solids and acidity, from the second week of storage tomatoes with TAQ began their ripening process more quickly than the other treatments, the weight loss could influence this carried out during ripening because although the treatment influenced gas exchange, delaying ripening, it did not achieve good moisture permeability and therefore showed greater dehydration and deterioration. TAQ exhibits good gas barrier properties, thereby maintaining product quality; however, its hydrophilic nature results in a low moisture barrier. Table 3 presents the results obtained regarding the behavior of humidity percentage during storage.

There were no significant differences ($p \leq 0.05$) in the percentage of humidity over time, as in the treatments carried out, the small fluctuations observed over time refer to the variability between the tomato samples presented by conditions specific to the product, such as soil quality, harvest period, crop characteristics, among others. Even so, a slight tendency to increase over time is observed in the humidity

**Table 3.** Behavior of tomato moisture content during storage

| Time (d) | Moisture content (% m/m) | | |
|---|---|---|---|
| | TC1 | TAQ | TLQ |
| 0 | 93.4 (0.3) ab | 93.4 (0.3) ab | 93.4 (0.3) ab |
| 7 | 91.1 (4.6) a | 90.5 (5.0) a | 93.38 (0.06) ab |
| 10 | 93.9 (0.6) ab | 94.2 (1.7) ab | 93.1 (0.1) ab |
| 14 | 93.4 (0.5) ab | 93.82 (0.007) ab | 95.2 (1.6) ab |
| 16 | 94.8 (1.0) ab | 96.8 (2.7) b | 94.70 (0.02) ab |

Mean (standard deviation); n= 2.

Different letters indicate significant difference ($p \leq 0.05$).

content, which may be related to the duration of the process. The predominant reactions are the ripening processes through hydrolysis, by which the polymer molecules in green fruits (starch, cellulose, and pectins), which are formed by the union of smaller molecules, or "monomers", are broken down by incorporating a water molecule and releasing these small units.

In Figure 5, the weight loss behavior during storage is observed for each treatment. A tendency to increase the percentage of weight loss over time is observed, which is a process associated with ripening.

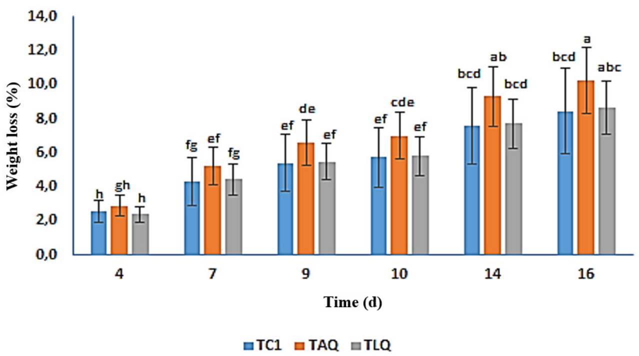


**Figure 5.** Weight loss behavior in tomatoes during storage. Error bars indicate standard deviation (n=3). Different letters indicate a significant difference ($p \leq 0.05$).

There were no significant differences between treatments ($p \leq 0.05$). These results were unexpected, considering that the mulches were supposed to act as barriers, minimizing these losses.

Although all the above demonstrated that the coatings in this study did not play an effective role in combating weight loss, an analysis of Figure 5 shows and considering as an index of shelf life completion in tomato, a physiological weight loss of 10% (Getinet & Seyoum, 2008), it can be said that the losses obtained did not compromise the quality of the stored fruits.

The average penetration distance results obtained for each treatment during storage are shown in Figure 6. Greater effectiveness in maintaining firmness is observed in the TLQ lot. Tomatoes subjected to the TLQ treatment showed the lowest overall penetration distance.

After 10 days of storage, considering the marketing cycle of this variety, they were the firmest tomatoes, maintaining this behavior for up to 16 days. Control tomatoes (TC1) were less firm than treated tomatoes, agreeing with results obtained by other authors (Devlieghere et al., 2004; Amigo, 2006; Díaz et al., 2010), who used chitosan as a structural support for the coverings.

From a quality perspective, the visual appearance of tomatoes is considered of utmost importance. Due to water loss, they deteriorate, causing dehydration and consequent wrinkling.

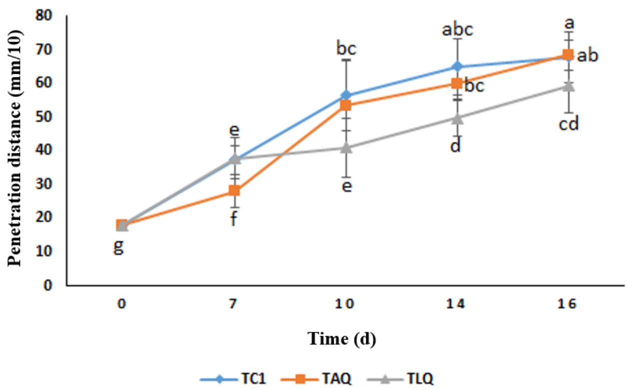


**Figure 6.** Penetration rate behavior during storage. Error bars indicate standard deviation (n=3). Different letters indicate a significant difference ($p \leq 0.05$).

In Figure 7, the results show the wrinkling losses that occurred in the tomatoes at the end of storage. The application of the TLQ treatment extended the shelf life of the tomatoes, as fewer of them were wrinkled. At the end of storage, no products showed a wrinkling percentage greater than 30%, unlike the other treatments. This shows the gas barrier effect and the permeability of this coating, which significantly influences fruit preservation.

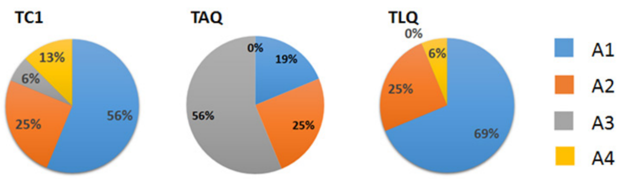


**Figure 7.** Wrinkling deterioration in tomatoes during storage.

The treatment that showed the highest percentage of wrinkled tomatoes (A3) at the end of the study was TAQ, in which 56% of the tomatoes exhibited greater deterioration due to wrinkling, resulting from the weight loss that occurred during storage. This treatment is not very permeable to moisture, so it cannot prevent dehydration of the fruit. Likewise, the concentration at which the treatments were applied must be taken into account (García et al., 2014). That is why chitosan films are made with the addition of essential oils to reduce water vapor permeability (Escalante et al., 2024).

Another aspect to consider in tomato deterioration is the physiological damage caused by fungi and microorganisms (Figure 8). In the control lot (TC1), the total number of damaged tomatoes (A4) was higher than in the other treatments, with the appearance of undesirable odors. The first damage caused by fungi occurred in the control lot within the first 5 days of storage, leading to product deterioration.

After 14 days of storage, fungal damage was again evident in a sample from TC1 and TLQ. The antimicrobial mechanism of action of chitin, chitosan, and their derivatives is not yet fully understood; however, studies conducted by Liu et al. (2009) demonstrated that chitosan increased the permeability of the external and internal membranes of bacterial cells to the point of rupture, with the subsequent release of cytoplasmic contents. The authors attribute this damaging or bactericidal effect to the electrostatic interaction between the positively charged amino groups of chitosan and the negatively charged phosphoryl groups of the phospholipid components of cell membranes.

**Figure 8.** Physiological damage in tomatoes due to the presence of fungi and deterioration due to wrinkling.

Bautista and Bravo (2004) evaluated the antifungal activity of chitosan with different degrees of polymerization in the development of soft rot caused by *Rhizopus stolonifer* in tomato, during a storage period of 48, 72 and 96 h at 14 ºC, indicating that the application of chitosan delayed the development of *R. stolonifer* during the last two evaluation periods concerning untreated fruit.

## Conclusions

The addition of chitosan salts did not significantly influence the variation in pH, soluble solids, or moisture content in tomatoes during storage. Coating with chitosan lactate enhanced the overall quality of the tomatoes, delaying the ripening process and positively affecting the maintenance of fruit firmness. It also resulted in the lowest percentage of tomatoes damaged by wrinkling. Coating with chitosan acetate significantly influenced the citric acid content in tomatoes, presenting the lowest maturity index at 16 days of storage. However, it was not effective as a barrier to weight loss; it was the treatment that showed the highest number of wrinkled tomatoes at the end of storage. The application of chitosan salts proved to be an effective means of antimicrobial control in tomatoes, inhibiting microbial growth during storage.

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**Conflicts of interest**

The authors declare that they have no conflicts of interest.

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**Data availability statement**

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

**Statement on the use of AI**

The authors acknowledge the use of generative AI and AI-assisted technologies to improve the readability and clarity of the article.

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