# *Spirogyra* residue-based edible coating for maintaining postharvest quality and safety of tomatoes

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## Abstract

Tomatoes are perishable and prone to postharvest deterioration, leading to quality and safety losses. This study aimed to evaluate the potential of a *Spirogyra* residue-based coating (SRC) as a natural treatment for maintaining the postharvest quality of tomatoes during storage at 4 °C and 25 °C for 21 days. Tomato samples were coated with the prepared SRC solution, whereas control samples were treated with distilled water. The results showed that at 4°C, SRC-coated tomatoes exhibited lower weight loss, maintained firmness, and reduced microbial growth compared to the control samples. At 25°C, the coating also delayed ripening and minimised spoilage, although quality changes occurred more rapidly than at 4°C. The coating effectively inhibited microbial proliferation, particularly total plate count, yeast and mold, while mitigating physical deterioration such as colour, firmness, and weight loss. These findings demonstrate that SRC can effectively delay physical changes and prevent microbial growth, thereby extending the postharvest quality of tomatoes.

**Keywords:** tomato, *Spirogyra* residue, coating, postharvest quality, food safety

## Introduction

Tomatoes are among the most widely consumed horticultural commodities worldwide, valued for their abundance of antioxidants, ascorbic acid, tocopherol, lycopene, β-carotene, and essential vitamins and minerals (Elsayed et al., 2022; Akhtar, Akhtar, Nazir, & Khalid, 2023). However, their commercial and nutritional value is constrained by a short postharvest shelf life of only 5–7 days, largely due to their high respiration rate, elevated water content, and ethylene production. Quality deterioration is further accelerated by environmental factors such as temperature and relative humidity, as well as microbial spoilage that leads to physiological and structural degradation (Li, Tao, & Zhang, 2017; Das, Vishakha, Das, Chakraborty, & Ganguli, 2022). As a result, approximately 50% of total tomato production is lost postharvest, with microbial contamination and improper handling during transport and storage contributing to nearly 30% of these losses. Such postharvest losses not only raise ecological concerns but also impose substantial economic challenges (Ruiz-Martínez, et al., 2020; Oluba, et al., 2022). Therefore, it is essential to develop practical methods for extending the shelf life of tomatoes.

Coating has emerged as an effective postharvest technology for maintaining the quality of fresh produce. Coatings are thin layers applied directly to the food surface, serving as barriers to moisture migration, gases such as $O_2$ and $CO_2$, respiration, and the development of physiological disorders in fruits. They also protect products from microbial contamination, extend shelf life, reduce deterioration, and minimize lipid oxidation and moisture loss (Suhag, Kumar, Petkoska, & Upadhyay, 2020; Priya, Thirunavookarasu, & Chidanand, 2023). In recent years, coatings have been studied for perishable food products such as fruits and vegetables, which are highly susceptible to water loss, mechanical damage, and sensory changes during storage, leading to economic losses. *Spirogyra* sp. contains polysaccharides and bioactive compounds that contribute to its antioxidant and antimicrobial properties (Belyagoubi, Belyagoubi-Benhammou, Atik-Bekkara, &

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Abdelouahid, 2022). A *Spirogyra*-based film has been shown to reduce water vapour permeability by 50% while maintaining better weight retention and firmness in okra during 5 days of storage at ambient temperature (Soiklom, Siri-anusornsak, Petchpoung, Soiklom, & Maneeboon, 2025). However, the use of *Spirogyra* residue as a natural coating for maintaining tomato postharvest quality and safety has not yet been investigated. has not yet been explored.

Therefore, this study investigates the application of a *Spirogyra* residue-based coating (SRC) to enhance postharvest quality and extend the shelf life of tomatoes stored at 4 °C and 25 °C for 21 days. The effectiveness of the coating was evaluated in terms of weight loss, colour (a*/b* ratio), firmness, titratable acidity, and microbial growth, with the aim of establishing *Spirogyra* residue as an alternative for postharvest preservation.

## Materials and Methods

### *Sample preparation*

Tomatoes (Roma, *Solanum lycopersicum*) were selected for the experiments based on uniformity in size and quality at the pink stage (a*/b* = 0.95). Any tomatoes showing impact injury, insect infestation, or pathogenic infections were removed. The tomatoes were purchased from a local market in Nonthaburi, Thailand, and washed with distilled water to remove surface residues then air-dried at ambient temperature using an electric fan for 15 min. The average initial quality parameters of the tomatoes were a firmness of 7.3 N and a titratable acidity of 0.65%.

### *Coating preparation*

The coating solution was prepared according to the method of Soiklom et al. (2025). *Spirogyra* powder was weighed to obtain a concentration of 20% (w/v) and mixed with 1% (w/v) chitosan to a final volume of 100 mL. The mixture was heated on a magnetic stirrer hotplate to 70 ± 5 °C, then filtered through Whatman filter paper to eliminate air bubbles, and then left to stand at room temperature for 1 h before application on the tomatoes.

The concentration of 20% (w/v) *Spirogyra* and 1% (w/v) chitosan was selected based on preliminary trials that yielded optimal coating thickness and adherence, consistent with the finding of Soiklom et al. (2025). Heating at 70°C facilitated polymer dissolution and enhanced solution homogeneity without compromising bioactive components.

### *Application of coatings on tomatoes*

The coating solutions were applied to the tomato surfaces using the dipping method. Tomatoes were immersed in the coating solution for 10 min, placed on a wire rack to drain for 2 min, and subsequently air-dried for 30 min. Control samples were immersed in distilled water instead of a coating solution, following the same coating time and procedures as the SRC-coated samples. All tomatoes were then packed in perforated low-density polyethylene bags (five tomatoes per bag per replication) and stored at 4 °C (RH = 85%) and 25 °C (RH = 65%) for 21 days.

### *Coated tomato characterisation*

#### *Colour*

The colour of the tomato samples was measured using a colorimeter (HunterLab; Ultrascan Pro; Restion, VA, USA).

*Weight loss*

Weight loss was determined based on the modified method described by Borges et al. (2023), using an analytical weighing balance (ATY224R; Shimadzu; Kyoto, Japan). The percentage of weight loss was calculated according to the following equation:

$$\text{Weight loss (\%)} = [(W_0 - W_t)/W_0] \times 100$$

where $W_0$ represents the initial weight of the sample and Wt denotes the sample weight measured at each storage interval.

*Firmness and toughness*

Firmness and toughness of the tomato samples were evaluated using a texture analyser (TA-HD Plus; Stable Micro System; Godalming, Surrey, UK) at three randomly selected points per sample. Firmness was reported as force (N), while toughness was expressed as force-time (N.s).

*Titratable acidity*

Titratable acidity (TA) was obtained by titrating homogenised tomato samples against 0.1 N NaOH up to pH 8.2 using phenolphthalein indicator. The results were expressed as the percentage of titratable acidity, calculated in terms of citric acid equivalent.

*Microbial growth*

Microbial enumeration in tomato samples was conducted following the modified method of the Bacteriological Analytical Manual (2001a and 2001b).

Total plate count (TPC) was determined using the pour plate technique. One mL of diluted sample was pipetted into plate count agar (PCA) dish, then incubated at 35 °C for 48 h. Colonies were counted from plates containing 25-250 colonies and expressed as log CFU/g.

Yeast and mold count was determined using the spread plate technique. Subsequently, 0.1 mL of diluted sample was spread onto dichloran rose bengal chloramphenicol (DRBC) agar plates. Plates were incubated at 25 °C for 5 days. Colonies were counted from plates containing 10–150 colonies, and expressed as log CFU/g.

*Statistical analysis*

All the investigations were performed in triplicate, and results are expressed as mean ± standard deviation. Statistical analysis was carried out using the SPSS version 14.0 for Windows software (IBM Corp; Armonk, NY, USA) to determine significant differences ($p < 0.05$).

## Results and Discussion

*Colour (a*/b* ratio)*

The a*/b* ratio increased significantly ($p < 0.05$) in both uncoated and SRC- coated tomatoes during the 21-day storage period at 4 °C and 25 °C (Table 1). At day 0, values were comparable between treatments (0.95–0.99); however, by day 21, the ratio had risen to 1.19 and 1.18 at 4 °C, and up to 1.43 at 25 °C. The faster increase observed at 25 °C indicates the accelerating effect of higher temperature on respiration and ripening-related metabolic processes, whereas cold storage effectively delayed colour changes. SRC coating slightly delayed early ripening (day 0–3), as indicated by lower initial a*/b* values compared to the control, but this difference diminished over time, with both groups reaching similar levels by day 21. These findings are consistent with previous reports that attribute the increasing a* values to chlorophyll degradation and lycopene accumulation during ripening (Vardanian et al., 2025; Ali et al., 2025). Several studies have further reported that the tomato colour index is primarily influenced by storage conditions, particularly temperature, given its sensitivity to ambient temperatures indicating the critical role of temperature in influencing tomato colouration. Moreover, this highlights the critical role of temperature, together with coating efficacy, in regulating postharvest quality (Khairi, Falah, Suyantohadi, Takahashi, & Nishina, 2015).

**Table 1** The a*/b* value of uncoated and SRC-coated tomatoes during storage time under 4 °C and 25 °C.

| Storage time (Day) | Uncoated | | SRC-coated | |
|---|---|---|---|---|
| | 4 °C | 25 °C | 4 °C | 25 °C |
| 0 | $0.96 \pm 0.01^{a}$ | $0.99 \pm 0.01^{a}$ | $0.95 \pm 0.02^{a}$ | $0.92 \pm 0.01^{a}$ |
| 3 | $1.00 \pm 0.01^{a}$ | $1.03 \pm 0.01^{b}$ | $0.99 \pm 0.01^{a}$ | $1.03 \pm 0.01^{b}$ |
| 7 | $1.05 \pm 0.01^{b}$ | $1.11 \pm 0.02^{c}$ | $1.05 \pm 0.01^{b}$ | $1.10 \pm 0.02^{c}$ |
| 14 | $1.15 \pm 0.02^{c}$ | $1.28 \pm 0.03^{d}$ | $1.14 \pm 0.02^{c}$ | $1.27 \pm 0.03^{d}$ |
| 21 | $1.19 \pm 0.02^{d}$ | $1.43 \pm 0.01^{e}$ | $1.18 \pm 0.01^{d}$ | $1.43 \pm 0.01^{e}$ |

Values are the mean ± standard deviation. Different superscript letters within the same column indicate significant differences ($p < 0.05$).

***Weight loss***

Weight loss in fruits primarily results from water loss, which is a key indicator of postharvest quality since even slight dehydration significantly affects fruit appearance (Singh, Saroj, & Kaur, 2024). The changes in weight loss of tomatoes during storage are presented in Figure 1A. Control samples consistently exhibited the highest weight loss at both 4 and 25 °C compared to those SRC-coated samples. After 7 days at 4 °C, weight losses were 2.51% in uncoated samples and 1.90% in SRC-coated samples. At the end of the storage period, these values increased to 13.26% and 10.14%, respectively. At 25 °C, uncoated tomatoes showed a 4.33% loss after 7 days, while SRC-coated tomatoes were 2.00%. After that, weight loss increased to 17.30% in uncoated and 12.02% in SRC-coated samples, respectively, at the end of storage time. Likewise, Soiklom et al. (2025) found that *Spirogyra* coatings significantly reduced weight loss in okra compared to uncoated samples after five days of storage. There were further reports that coating can regulate respiration by forming a barrier on the surface, thereby limiting oxygen and carbon dioxide exchange between the sample and its environment and prolonging shelf life.

The reduction in weight loss of SRC-coated samples can be attributed to the coating material functioning as a semi-permeable barrier. This barrier effectively restricts the movement of moisture, oxygen, carbon dioxide, and solute, which reducing the rates of transpiration, respiration, and oxidative reactions (Suhag et al., 2020; Priya et al., 2023). The polysaccharides in the *Spirogyra* are hypothesised to form a thin, semi-permeable film matrix. This film creates a modified environment around fruit by selectively modulating the exchange of oxygen and carbon dioxide, which is crucial for extending the postharvest shelf life (Suhag et al., 2020). Furthermore, it is important to note that a portion of the overall weight loss also stems from the release of carbon dioxide as a byproduct of respiration, reflecting the mass balance between oxygen uptake and carbon dioxide emission (Attar, Sedaghat, Pasban, Yeganehzad, & Hesarinejad, 2023).

***Firmness and toughness***

Firmness and toughness are key textural attributes of tomatoes, primarily perceived through touch, and both parameters declined progressively during storage at 4 and 25 °C in both uncoated and SRC-coated tomatoes (Figure 1B). At 4 °C, the firmness of control samples decreased from 7.35 to 4.83 N, while toughness declined from 22.64 to 15.14 N·s. Similarly, SRC-coated samples exhibited reductions from 6.96 to 4.63 N in firmness and from 24.02 to 16.51 N·s in toughness by the end of storage. At 25 °C, the firmness of uncoated tomatoes dropped from 7.24 to 3.75 N, with toughness decreasing from 22.56 to 15.45 N·s. In contrast, SRC-coated tomatoes showed a slower decline, with firmness reducing from 7.43 to 5.02 N and toughness from 23.04 to 15.78 N·s at the end of storage.

Cold storage is a well-established method to retard tissue softening, and the application of SRC further reduced the rate of firmness loss in this study. The slower textural decline observed in coated samples is attributed to the suppression of cell wall degrading enzymes, particularly pectin methyl esterase (PME) and polygalacturonase (PG) (Kabir et al., 2020). The activity of these enzymes generally depends on respiration rate and ethylene concentration (Sinha et al., 2019). The SRC layer creates a micro-modified atmosphere, which reduces oxygen availability and slows respiration, thereby downregulating the synthesis and activity of these hydrolytic enzymes. Furthermore, the coating also helps maintain turgor pressure by acting as a barrier against water loss, particularly through the stem scars (Fich, Fisher, Zamir, & Rose, 2020), which contributes to the overall retention of firmness.

Consequently, SRC-coated tomatoes retained approximately 8–12% higher firmness and 6–10% higher toughness than uncoated samples throughout storage, confirming that the coating effectively retarded textural deterioration through both physical barrier and biochemical inhibition mechanisms. These findings are consistent with studies reporting that edible coatings create a micro-modified atmosphere and enzymatic suppression that jointly contribute to the maintenance of fruit firmness during storage (Ruelas-Chacon et al., 2017; Wu, Tang, & Fan, 2024). Other research also supports the efficacy of polysaccharide-based coatings in preserving firmness, such as the use of CMC and *Osmunda japonica* Thunb polysaccharide, which resulted in a notable difference in firmness reduction between coated (44.2%) and uncoated (63.7%) samples (Zhang, Zhang, Liu, Du, & Tian, 2019). Similarly, composite coatings using chitosan-pullulan were also effective in maintaining firmness during storage (Kumar, Neeraj, & TrajkovskaPetkoska, 2021).

***Titratable acidity***

Titratable acidity, expressed as citric acid percentage, serves as an indicator of organic acid reserves in fruits. These reserves naturally decrease during postharvest storage as the organic acids are consumed as substrates for respiratory metabolism (Singh et al., 2024). In this study, titratable acidity decreased in all samples throughout storage at both temperatures. As expected due to accelerated metabolic activity at higher temperatures, the rate of decrease was fast at 25 °C compared to 4 °C. This temperature-dependent trend highlights the accelerated metabolic activity at higher temperatures, leading to faster utilisation of organic acids. However, the coated samples maintained higher titratable acidity compared to the control treatment throughout storage.

At 4 °C, the titratable acidity of the SRC-coated tomatoes decreased from 0.70 to 0.55%, whereas the control treatment reduced from 0.66 – 0.54% (Figure 1D). These results suggest that the coating acted as a semi-permeable barrier, reducing respiration and slowing the consumption of organic acids.

At 25 °C, similar trends in titratable acidity were observed, with the reduction occurring more rapidly than at 4 °C. Nevertheless, SRC-coated tomatoes consistently retained higher acidity than the uncoated samples. At the end of storage time, the titratable acidity of the SRC-coated samples decreased from 0.68 to 0.53%, whereas that of the uncoated samples decreased from 0.65 to 0.53% (Figure 1B). The ability of the coating to delay acidity loss may be attributed to its role in reducing ethylene production, thereby slowing respiration and organic acid utilisation. A similar observation was reported by Abhirami et al. (2020) that the coatings maintain titratable acidity by suppressing respiratory metabolism.

The higher retention of acidity in coated tomatoes indicates an extended maintenance of the quality and metabolic balance during storage. Since organic acids serve as key substrates in enzyme-catalysed reactions of aerobic respiration, their decline is expected as ripening progresses. This reduction not only marks the advancement of maturity but also contributes to the perception of increased sweetness in fruits. Therefore, coated samples, by slowing the decline in acidity, help to postpone ripening. In addition, Aly & Maraei (2024) reported that higher titratable acidity may also be the reason for the formation of carboxylic acids via dark fixation of carbon dioxide, further supporting the role of coatings in modulating acid dynamics during storage.

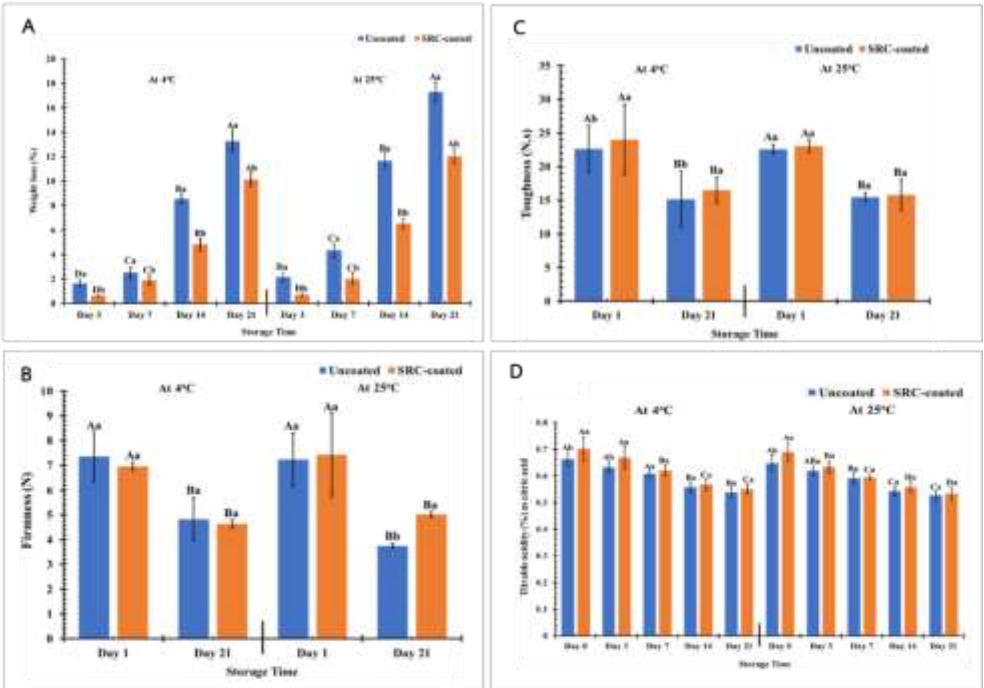


**Figure 1** Weight loss percentage (A), firmness (B), toughness (C), and titratable acidity (D) of uncoated and SRC-coated tomatoes during storage under 4 °C and 25 °C. Different capital letters indicate significant ($p < 0.05$) differences among storage times, and different lowercase letters indicate significant ($p < 0.05$) differences between treatments.

*Microbial growth*

The microbiological quality of tomatoes during storage was evaluated using the plate count method, and the results are summarised in Table 2. After 21 days of storage, SRC coating significantly suppressed microbial proliferation compared to the uncoated control at both temperatures. At 4 °C, uncoated tomatoes exhibited a total plate count (TPC) of 6.11 log CFU/g and yeast and mold counts (YMC) of 4.02 log CFU/g, whereas SRC-coated tomatoes showed significantly lower values of 4.66 log CFU/g and 3.42 log CFU/g, respectively. These results indicate a 27.3% reduction in TPC and a 14.9% reduction in YMC compared with the uncoated control. At 25 °C, the TPC and YMC of uncoated tomatoes reached 9.26 log CFU/g and 5.98 log CFU/g, respectively, while those of SRC-coated tomatoes were markedly lower at 5.85 log CFU/g and 3.90 log CFU/g, representing reductions of 36.8% and 34.8%, respectively.

The significant microbial suppression in coated samples can be explained by both physical barrier effects and biochemical antimicrobial mechanisms. The SRC layer acts as a semi-permeable membrane, reducing oxygen permeability and simultaneously increasing internal carbon dioxide concentrations. This modulation of the internal gaseous environment slows metabolic activity and limits the growth of aerobic spoilage microorganisms (Kabir et al., 2020; Khalid et al., 2022). Moreover, *Spirogyra* biomass further contributes through biochemical inhibition, containing bioactive compounds such as phenolics, flavonoids, and sulfated polysaccharides. These compounds are reported to possess antimicrobial activity by directly disrupting microbial cell walls and inhibiting the metabolic enzymes necessary for replication (Soiklom et al., 2025; Priya et al., 2023).

These combined effects, including the modulation of the internal gaseous environment and biochemical inhibition, contributed to the lower microbial counts observed in SRC-coated tomatoes. The effective suppression of microbial spoilage indirectly supported the overall maintenance of firmness and extension of shelf life, clearly demonstrating the synergistic role of coating in controlling both enzymatic inhibition and microbial control.

To provide a comprehensive overview, Table 3 summarises the quality parameters of uncoated and SRC-coated tomatoes after 21 days of storage at both temperatures. The SRC-coated samples exhibited lower weight loss and microbial counts, as well as higher firmness, particularly at 25 °C, compared with the uncoated control. Titratable acidity remained relatively unchanged between treatments, indicating that the coating primarily contributed to maintaining physical integrity and microbiological stability rather than influencing acid metabolism.

**Table 2** Microbial growth of uncoated and SRC-coated tomatoes during storage time under 4°C and 25°C.

| Temperature (°C) | Treatment | Total plate count (log CFU/g) | Yeast and mold (log CFU/g) |
|---|---|---|---|
| 4 | Uncoated | 6.11±0.23$^{a}$ | 4.02±0.12$^{a}$ |
| | SRC-coated | 4.66±0.07$^{b}$ | 3.42±0.10$^{b}$ |
| 25 | Uncoated | 9.26±0.13$^{a}$ | 5.98±0.05$^{a}$ |
| | SRC-coated | 5.85±0.21$^{b}$ | 3.90±0.09$^{b}$ |

Values are the mean ± standard deviation. Different lowercase letters indicate significant ($p < 0.05$) differences between treatments.

**Table 3** Comparison of quality parameters between uncoated and SRC-coated tomatoes at 4 °C and 25 °C after 21 days of storage.

| Parameter | At 4 °C | | At 25 °C | |
|---|---|---|---|---|
| | Uncoated | SRC-coated | Uncoated | SRC-coated |
| Weight loss (%) | 13.27±0.90$^{a}$ | 10.14±0.55$^{b}$ | 17.30±0.80$^{a}$ | 12.02±0.61$^{b}$ |
| Firmness (N) | 4.83±0.86$^{a}$ | 4.63±0.17$^{a}$ | 3.75±0.09$^{b}$ | 5.02±0.11$^{a}$ |
| Titratable acidity (%) | 0.54±0.02$^{a}$ | 0.55±0.02$^{a}$ | 0.53±0.02$^{a}$ | 0.53±0.02$^{a}$ |
| Total plate count (log CFU/g) | 6.11±0.23$^{a}$ | 4.66±0.07$^{b}$ | 9.26±0.13$^{a}$ | 5.85±0.21$^{b}$ |
| Yeast & Mould (log CFU/g) | 4.02±0.12$^{a}$ | 3.42±0.10$^{b}$ | 5.98±0.05$^{a}$ | 3.90±0.09$^{b}$ |

Values are the mean ± standard deviation. Different superscript letters within the same row indicate significant differences ($p < 0.05$).

## Conclusions

*Spirogyra* residue-based coating (SRC) is a natural and effective strategy for maintaining the postharvest quality of tomatoes during storage at both 4 °C and 25 °C. The application of the coating delayed colour changes and significantly preserved firmness, indicating a slower ripening process. By acting as a semi-permeable barrier that limited respiration and moisture loss, the SRC effectively reduced weight loss. Furthermore, SRC-coated tomatoes retained higher titratable acidity than uncoated samples, reflecting a slower utilisation of organic acids during storage.

The microbial quality of tomatoes was also improved by the SRC, as coated samples showed lower total plate counts and yeast and mold counts. This microbial inhibition can be attributed to the synergistic action of both the physical barrier properties and the inherent antimicrobial properties compounds present in *Spirogyra*. These findings demonstrate that the SRC can effectively delay physical and biochemical changes while preventing microbial proliferation, which significantly lowers the risk of postharvest spoilage in tomatoes.

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