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Effects of Storage Temperature and Packaging on the Postharvest Quality of Tomato (*Solanum lycopersicum* L.)

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) is highly perishable because respiration, transpiration, and ripening continue after harvest. This study evaluated six combinations of packaging and storage temperature for preserving tomato quality. A completely randomized design was used with unpackaged, polyethylene-packaged, or newspaper-wrapped fruit stored at ambient temperature or 15 °C. Each treatment combination was replicated four times, resulting in 24 experimental units. Weight loss, firmness, total soluble solids, vitamin C, carotenoid content, and sensory scores for texture and colour were evaluated during 14 days of storage. Treatment combinations significantly affected the measured quality attributes. Polyethylene packaging at 15 °C resulted in the lowest weight loss, greatest firmness and vitamin C content, and highest texture score. It also delayed colour development and carotenoid accumulation, indicating slower ripening. Under the conditions tested, polyethylene packaging at 15 °C was the most effective treatment for maintaining the physical, chemical, and sensory quality of Mustafi tomatoes during 14 days of storage.

Keywords: cold storage, fruit quality, polyethylene packaging, postharvest physiology, shelf life

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is an economically important horticultural crop consumed both fresh and in processed products. The fruit supplies lycopene, vitamin C, vitamin A, minerals, fibre, and other antioxidant compounds. Its moisture content, which may reach approximately 94%, nevertheless makes it highly susceptible to water loss, softening, colour change, and decay during storage (Maslahatul *et al*., 2024). As a climacteric fruit, tomato exhibits increased respiration and ethylene production during ripening, which accelerates senescence (Poudel *et al*., 2022). At the farm level, harvested tomatoes are commonly placed in cardboard boxes without additional postharvest treatment. Such limited handling can cause substantial losses for growers, distributors, and other actors in the horticultural supply chain (Novita & Suyatma, 2022).

Postharvest deterioration is largely driven by the physiological activity that

continues after the fruit has been detached from the plant. Continuous respiration and transpiration gradually alter the physical and chemical properties of tomatoes during storage (Zhang *et al*., 2023). Appropriate packaging can limit mechanical injury, reduce moisture loss, and modify gas exchange between the fruit and its surroundings. Polyethylene is lightweight, widely available, and relatively effective at restricting water-vapour transfer. Johansyah *et al*. (2014) reported that plastic packaging can delay tomato ripening and reduce weight loss and colour change. Newspaper offers a low-cost alternative and protects fruit against direct abrasion; however, its porous structure provides a weaker barrier to water vapour than polyethylene (Ashadi *et al*., 2022; Asjulia & AS, 2023; Fitriani *et al*., 2022).

Previous studies therefore indicate that storage temperature and packaging can influence tomato weight loss, moisture retention, firmness, colour development, and storage life.

Earlier research has shown that polyethylene packaging at low temperature can reduce tomato weight loss and preserve firmness more effectively than storage without packaging (Maslahatul *et al*., 2024). Nevertheless, direct comparisons among polyethylene, newspaper, and unpackaged treatments under different temperature regimes remain limited. Further examination is particularly needed to explain how these combinations affect physicochemical characteristics and consumer acceptance throughout storage.

This study aimed to identify the treatment combination of packaging type and storage temperature that best maintained tomato quality during 14 days of storage. The evaluated outcomes were weight loss, firmness, total soluble solids, vitamin C, carotenoid content, and sensory scores for colour and texture.

MATERIALS AND METHODS

Time and Location

The experiment was conducted during April 2026 in a storage facility in Watubelah Village and at the Postharvest Laboratory, Faculty of Agriculture, Swadaya Gunung Jati University, Cirebon, West Java. Mustafi tomatoes were harvested from farms in Sangiang Village, Banjaran Subdistrict, Majalengka Regency.

Research Materials and Equipment

The experimental materials consisted of Mustafi tomatoes without visible pest damage, disease symptoms, or physical injury; distilled water; polyethylene bags; newspaper; ascorbic acid; and iodine solution. The equipment included a digital balance, thermometer, filter cloth, microfibre cloth, UV–Vis spectrophotometer, handheld refractometer, penetrometer, and stationery.

Research Method

The experiment used a completely randomized design with six treatment combinations derived from two storage temperatures and three packaging conditions (Figure 1). A total of 240 tomatoes were divided among ambient storage (mean 29.2 °C and 70% relative humidity) and cooled storage (mean 15 °C and 78% relative humidity) (Figure 2). Within each temperature, fruit were stored unpackaged, in polyethylene bags, or wrapped in newspaper. Each treatment combination was replicated four times, with 10 tomatoes per experimental unit, producing 24 experimental units. Storage lasted 14 days. The randomisation procedure, use of destructive versus repeated measurements, and allocation of fruit to each analytical test should be documented in the final submission.



(1) (2) (3)

Figure 1. Types of packaging used: unpackaged (1), polyethylene packaging (2), Newspaper packaging (3)



(1) (2)

Figure 2. Ambient-temperature storage area (1) and cold-storage chamber (2)

Observation Parameters

Weight Loss (%)

Tomato weight was measured with a digital balance before storage and on days 1, 4, 9, and 14. Percentage weight loss was determined using the following equation:

$$\text{Weight Loss} = \frac{Ba-Bb}{Ba} \times 100\%$$

Notes:
Ba = weight on day 0 (g)
Bb = weight on day n (g)

Firmness (kg/cm²)

Firmness was assessed on days 1, 4, 9, and 14 using a penetrometer. The probe was positioned perpendicular to the tomato surface and pressed into the tissue until the maximum reading was obtained. After each measurement, the probe was cleaned and the instrument was reset to zero. The instrument model, probe diameter, penetration depth and speed, measurement location, number of readings per fruit, and calibrated reporting unit should be stated in the final submission.

Total soluble solids (°Brix)

Total soluble solids were measured with an Atago refractometer covering a range of 0–60 °Brix on days 1, 4, 9, and 14. Juice was extracted from the central portion of each tomato, and several drops were placed on the refractometer prism. The reading was recorded directly in °Brix. The prism was subsequently rinsed with distilled water, dried, and recalibrated before the next sample. Each sample was measured twice to improve the reliability of the result (Zahroh *et al*., 2023).

Vitamin C (mg/100 g)

Vitamin C was determined on days 1 and 14 by iodometric titration with 0.01 N iodine and starch as the endpoint indicator. Each sample was titrated in triplicate, and vitamin C content was calculated as mg/100 g from the volume of iodine consumed. The calculation followed the procedure described by Breemer & Pattiruhu (2025), using the following equation:

$$\text{Vitamin C (mg/100 g)} = \frac{VI_2 \times Kl \times FP}{M} \times 100$$

Notes:
VI_2 = volume of iodine used (mL)
KI = iodine calibration
FP = dilution factor
M = sample weight (g)

Carotenoids (mg/100 g)

Carotenoid content was determined using UV–Vis spectrophotometry on days 1 and 14. Because carotenoids contribute to yellow, orange, and red colour development, their concentration was used as an indicator of ripening. The final submission must report the sample mass, extraction solvent and volume, extraction conditions, measurement wavelength, blank, calibration method or extinction coefficient, calculation equation, and number of analytical replicates.

Organoleptic

Sensory changes in tomato colour and texture were assessed on day 7 by 10 untrained adult panellists. Texture scores ranged from very soft to firm, whereas colour scores described progression from greenish red to bright red. The final submission should state the sample-coding and presentation procedure, serving conditions, randomisation, informed-consent process, and ethical approval or exemption.

Data Analysis

Sensory scores were summarised descriptively. For the remaining variables, treatment-combination means were evaluated by analysis of variance, followed by Duncan's Multiple Range Test at $\alpha = 0.05$ when the overall treatment effect was significant. Analyses were performed using IBM SPSS Statistics. Before submission, the authors should specify the software version, experimental unit, assumption tests, and treatment of repeated measurements over time. Separate effects of temperature, packaging, and their interaction should be reported only if a factorial model was fitted.

RESULTS AND DISCUSSION

Weight Loss

Weight loss increased during storage in all treatments, but the magnitude differed significantly among treatment combinations. Polyethylene-packaged tomatoes stored at 15 °C consistently showed the lowest weight loss, ranging from 0.00% to 1.11%. Unpackaged fruit stored at ambient temperature showed the greatest loss, increasing from 1.22% on day 1 to 10.23% on day 14 (Table 1).

The low water-vapour permeability of polyethylene helps retain humidity within the package and narrows the vapour-pressure difference between the tomato surface and the surrounding air. This condition restricts transpiration and stabilizes fruit weight.

Storage at 15 °C further reduces respiration, so the consumption of metabolic substrates proceeds more slowly than at room temperature (Poudel *et al*., 2022; Zhang *et al*., 2023). Iflah *et al*. (2012) similarly observed lower weight loss in polyethylene-packaged tomatoes than in fruit held in materials with greater water-vapour permeability. Pega *et al*. (2021) also showed that regulating temperature and the atmosphere surrounding the fruit can suppress respiration and reduce postharvest weight loss.

The substantial weight loss of unpackaged tomatoes can be explained by their direct exposure to ambient air, which allows moisture to evaporate readily from the surface. Newspaper also provides limited protection because its pores permit water-vapour movement and the paper itself may absorb moisture released by the fruit. Consequently, neither treatment maintains a consistently humid microenvironment. This interpretation agrees with Poudel *et al*. (2022), who reported that polyethylene packaging reduced tomato weight loss compared with unpackaged storage.

Table 1. Effect of temperature and packaging type on weight loss

No	Treatment	Weight Loss (%)			
		Day 1	Day 4	Day 9	Day 14
1	Unpackaged + room temperature	1.22 d	4.56 b	7.73 b	10.23 c
2	Polyethylene + room temperature	0.22 b	0.72 a	1.32 a	1.92 a
3	Newspaper + room temperature	0.80 c	4.55 b	6.57 b	9.08 b
4	Unpackaged + 15 °C	0.82c	4.45 b	7.26 b	9.97 bc
5	Polyethylene + 15 °C	0.00 a	0.38 a	0.67 a	1.11 a
6	Newspaper + 15 °C	0.79 c	4.23 b	7.11 b	9.63 bc

Note: Numbers followed by the same letter in the same column indicate no significant difference (DMRT 5%)

Firmness

Firmness decreased during storage in all treatments, but the rate differed among treatment combinations. Tomatoes packaged in polyethylene and stored at 15 °C retained the highest firmness, with values of 1.77–1.86 kg cm^{-2} as currently reported. The reporting unit must be verified against the penetrometer calibration before publication (Table 2).

The capacity of polyethylene to preserve firmness is closely associated with moisture retention and the maintenance of cell turgor. Excessive water loss reduces turgor pressure, causing tissues to wilt and soften. By limiting water-vapour movement, polyethylene slows this process and helps preserve cellular structure. Low temperature provides an additional benefit by reducing respiration, ethylene production, and the activity of enzymes involved in pectin and cell-wall degradation. Fitriani *et al*. (2022) explained that higher storage temperatures accelerate metabolism, moisture loss, and softening. Consistent with this mechanism, Dladla and Workneh (2023) found that packaged tomatoes kept under cool conditions retained firmness better than unpackaged fruit at room temperature. Li *et al*. (2025) likewise reported that low temperature delays cell-wall breakdown and tomato softening.

The poor firmness of unpackaged fruit at room temperature in the present study reflects its greater water loss and more rapid respiratory activity. Newspaper, whether used at room temperature or 15 °C, was less effective than polyethylene because it could not maintain a stable humid microenvironment. Overall, polyethylene

packaging combined with 15 °C storage offered the strongest protection against softening (Quinet *et al*., 2019).

Table 2. Effect of temperature and packaging type on firmness

No	Treatment	Firmness kg/cm² N			
		Day 1	Day 4	Day 9	Day 14
1	Unpackaged + room temperature	1.59 a	1.53 a	1.41 a	1.31 a
2	Polyethylene + room temperature	1.80 b	1.77 bc	1.70 cd	1.61 c
3	Newspaper + room temperature	1.72 ab	1.63 ab	1.64 bcd	1.51 bc
4	Unpackaged + 15 °C	1.78 b	1.61 ab	1.51 ab	1.45 b
5	Polyethylene + 15 °C	1.86 b	1.81 c	1.79 d	1.77 d
6	Newspaper + 15 °C	1.80 b	1.67 abc	1.61 bc	1.56 bc

Note: Numbers followed by the same letter in the same column indicate no significant difference (DMRT 5%)

Total Soluble Solids

Total soluble solids generally increased as ripening progressed, although the extent differed among treatment combinations. Unpackaged tomatoes at ambient temperature reached the highest final value (4.00 °Brix), whereas tomatoes stored in polyethylene at 15 °C maintained the lowest and most stable values (3.00–3.12 °Brix) (Table 3).

The relatively low and stable TSS values of tomatoes stored in polyethylene at 15 °C indicate delayed ripening. During maturation, complex carbohydrates, including starch and other polysaccharides, are converted into soluble sugars, causing TSS to rise. Tigist and Workneh (2013) described this carbohydrate conversion as a major reason for increasing TSS during tomato storage. Polyethylene creates a modified microenvironment by restricting gas exchange, while cooling slows respiration and other metabolic reactions. Together, these conditions reduce the rate at which simple sugars are formed and therefore moderate the increase in TSS.

Higher TSS values in the other treatments are consistent with more rapid ripening. In unpackaged fruit at room temperature, respiration and transpiration were not restricted, allowing physiological changes to proceed faster. Newspaper, at either temperature, did not provide the same protection as polyethylene because its porous and moisture-absorbing structure could not maintain a stable atmosphere around the tomatoes.

Table 3. Effect of temperature and packaging type on total soluble solids

No	Treatment	Total Soluble Solids °Brix			
		Day 1	Day 4	Day 9	Day 14
1	Unpackaged + room temperature	3.25 a	4.10 c	4.87 c	4.00 b
2	Polyethylene + room temperature	3.25 a	3.25 ab	3.25 abc	3.62 b
3	Newspaper + room temperature	3.25 a	3.33 ab	3.50 abc	3.75 b
4	Unpackaged + 15 °C	3.15 a	3.37 ab	3.62 bc	4.00 b
5	Polyethylene + 15 °C	3.00 a	3.00 a	3.00 a	3.12 a
6	Newspaper + 15 °C	3.12 a	3.42 ab	3.45 ab	3.62 b

Note: Numbers followed by the same letter in the same column indicate no significant difference (DMRT 5%)

Vitamin C

Vitamin C increased between the first and final observations in all treatments, although the magnitude differed significantly. At day 14, tomatoes packaged in polyethylene and stored at 15 °C contained the most vitamin C, reaching 16.04 mg/100 g. The lowest final value, 11.31 mg/100 g, occurred in unpackaged tomatoes kept at room temperature (Table 4).

The higher vitamin C content retained by polyethylene-packaged tomatoes at 15 °C may be attributed to slower metabolic reactions and reduced activity of enzymes involved in ascorbic acid degradation. Vitamin C can accumulate during particular stages of ripening before declining as senescence advances (Davey *et al*., 2000). Cooling suppresses oxidative and enzymatic reactions, while polyethylene limits gas exchange and may create an atmosphere with less O_2 and slightly more CO_2 around the fruit (Mutu *et al*., 2023). These combined effects can slow ascorbic acid oxidation. Breemer & Pattiruhu (2025) similarly concluded that low temperature and packaging capable of modifying gas exchange contribute to vitamin C retention in tomatoes.

Lower vitamin C levels in unpackaged fruit reflect its greater exposure to oxygen and the faster metabolic activity associated with storage without a protective barrier. Newspaper did not provide comparable protection because air could continue to move through its porous structure.

Table 4. Effect of temperature and packaging type on vitamin C

No	Treatment	Vitamin C mg/100 g	
		Day 1	Day 14
1	Unpackaged + room temperature	6.31 ab	11.31 a
2	Polyethylene + room temperature	6.97 ab	12.89 a
3	Newspaper + room temperature	6.58 ab	12.70 a
4	Unpackaged + 15 °C	6.02 a	12.47 a
5	Polyethylene + 15 °C	7.52 b	16.04 b
6	Newspaper + 15 °C	6.50 ab	13.19 a

Note: Numbers followed by the same letter in the same column indicate no significant difference (DMRT 5%)

Carotenoids

Carotenoid content rose during storage as the tomatoes ripened, and the final values differed according to packaging and temperature. Unpackaged fruit stored at room temperature showed the highest concentration on day 14, at 0.035 mg/100 g. The lowest concentration, 0.018 mg/100 g, was recorded in tomatoes enclosed in polyethylene and held at 15 °C (Table 5).

Increasing carotenoid content is characteristic of tomato ripening. Chlorophyll is progressively degraded while carotenoids, especially lycopene, accumulate and produce the red surface colour (Álvarez-Pérez *et al*., 2025). Both storage temperature and ripening metabolism influence lycopene formation (Boulaajine & Hajjaj, 2024), and Distefano *et al*. (2020) confirmed that temperature affects carotenoid development. Polyethylene can further delay this process by altering the atmosphere around the fruit. Lower oxygen and higher carbon dioxide concentrations reduce respiration, ethylene activity,

chloroplast-to-chromoplast conversion, and lycopene synthesis.

Combining polyethylene packaging with storage at 15 °C therefore delayed carotenoid accumulation by slowing respiration and ripening, leaving the fruit at an earlier stage of colour development. Fagundes *et al*. (2015) reported a similar response under modified-atmosphere packaging, in which reduced respiration and ethylene production postponed lycopene formation. Conversely, the high carotenoid level of unpackaged tomatoes at room temperature indicates faster chlorophyll degradation and lycopene synthesis. Newspaper was less effective because its porous structure allowed continued gas exchange.

Table 5. Effect of Temperature and Packaging Type on Carotenoid Content

No	Treatment	Carotenoids mg/100 g	
		Day 1	Day 14
1	Unpackaged + room temperature	0.006 a	0.035 b
2	Polyethylene + room temperature	0.006 a	0.022 a
3	Newspaper + room temperature	0.005 a	0.029 ab
4	Unpackaged + 15 °C	0.006 a	0.028 ab
5	Polyethylene + 15 °C	0.005 a	0.018 a
6	Newspaper + 15 °C	0.005 a	0.025 ab

Note: Numbers followed by the same letter in the same column indicate no significant difference (DMRT 5%)

Organoleptic

Sensory evaluation was used to describe panel-perceived colour and texture. The scores differed among the six treatment combinations (Table 6).

Color

Tomato colour provides a visible indication of ripening and is associated with carotenoid accumulation. Unpackaged fruit stored at ambient temperature received a colour score of 4, corresponding to the “bright red” category. Newspaper-wrapped fruit at ambient temperature, unpackaged fruit at 15 °C, and newspaper-wrapped fruit at 15 °C each scored 3. Polyethylene-packaged fruit at both temperatures scored 2, consistent with delayed red-colour development. These scores describe colour intensity and should not be interpreted as hedonic preference unless preference was measured separately.

Texture

Texture is an important determinant of tomato quality and consumer acceptance. Polyethylene-packaged tomatoes at both room temperature and 15 °C achieved the highest texture score of 4. Newspaper treatments at both temperatures scored 3, whereas unpackaged fruit scored 2. The high acceptance of polyethylene-packaged fruit reflects the ability of this material to reduce water loss and preserve cellular turgor, thereby delaying softening. In contrast, unpackaged tomatoes lost moisture more readily and developed a softer texture. These results support the use of suitable packaging to maintain tomato texture during storage (Majidi *et al*., 2014).

Table 6. Descriptive organoleptic test of texture and color by panelists

No	Treatment	Texture	Colour
1	Unpackaged + room temperature	2	4
2	Polyethylene + room temperature	4	2
3	Newspaper + room temperature	3	3
4	Unpackaged + 15 °C	2	3
5	Polyethylene + 15 °C	4	2
6	Newspaper + 15 °C	3	3

Note: Texture was rated on a 1–4 scale, where 1 = very soft, 2 = soft, 3 = somewhat hard, 4 = hard (fresh), while color was rated on a 1–4 scale, where 1 = greenish red, 2 = yellowish red, 3 = even red, 4 = bright red

CONCLUSION

Among the six treatment combinations, polyethylene packaging at 15 °C provided the most consistent preservation of Mustafi tomatoes during 14 days of storage. This treatment minimised weight loss, maintained the highest firmness and vitamin C content, limited the increase in total soluble solids, retained texture, and delayed carotenoid accumulation and red-colour development. The recommendation is limited to the cultivar, packaging conditions, storage environments, and duration tested. Validation of decay incidence, microbial safety, condensation, economic feasibility, and performance at commercial scale is required before broader application.

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