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Research Article

Effects of Temperature and Polyethylene Plastic Packaging on Physicochemical Changes and Antioxidant Properties of Tomato During Storage

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ABSTRACT

This study determined the effects of different storage temperatures and packaging on the physicochemical changes and antioxidant properties of tomatoes during storage in two tomato species (*Lycopersicon esculentum* Mill. tomato and *Solanum lycopersicum* var. *Cerasiforme* cherry tomato). Samples underwent storage process with different temperatures of 4 °C and room temperature (25 °C); with or without polyethylene plastic packaging. The physicochemical changes studied include weight, color, firmness, and total soluble solids (TSS), while the antioxidant properties studied include lycopene content, ascorbic acid content, total phenolic content (TPC), and free radical scavenging activity (2,2-Diphenyl-1-picrylhydrazyl, DPPH), measured at three-time points (day 1, 8, 15). Based on the two-way ANOVA, both temperature and packaging factors play an important role in the physicochemical changes and antioxidant properties of both tomato species. For tomatoes, the temperature had a significant ($p<0.05$) effect on all measurements, except for redness value (a*) and ascorbic acid content ($p>0.05$). While packaging had a significant ($p<0.05$) effect on all measurements, excluding the ascorbic acid and TPC ($p>0.05$). For cherry tomatoes, the temperature had a significant ($p<0.05$) effect on all measurements, not including ascorbic acid content ($p>0.05$). Whereas packaging had a significant ($p<0.05$) effect on all measurements, except for TPC ($p>0.05$). For both samples studied, temperature and packaging factors had significant interactions ($p<0.05$) on all measurements, except for ascorbic acid and TPC ($p>0.05$). In conclusion, storage at a low temperature of 4 °C with the packaging was found to be able to maintain the physicochemical and antioxidant properties in both tomato species.

Key words: Antioxidants, packaging, physicochemical, storage temperature, tomato

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INTRODUCTION

The commercialization of fresh tomatoes is often closely linked to the duration between production and distribution to consumers (Distefano, 2020). As soon as the fruit is separated from the tree until it reaches the consumer, post-harvest maturation or aging occurs (Pott *et al*., 2020). The storage method and condition are crucial because tomatoes are climacteric, which is biologically still active post-harvest (Chen *et al*., 2020). The moisture content in tomatoes makes it often has a high rate of metabolic decline in ambient air (Zekrehiwot *et al*., 2017). This is indicated by obvious changes in color, firmness, sugar, acidity, and maturity.

In the context of storage, the temperature is a key factor in ensuring the quality of fresh products is guaranteed throughout the distribution chain. Crops such as tomatoes should be stored at low temperatures to ensure the temperature is ideal to slow down the ripening process. Nevertheless, the storage temperature should not be too low to ensure no or only minimal effects on the organoleptic and nutritional characteristics produced. Storage at low temperatures is also a method often used by tomato handlers, to increase the shelf life of tomatoes (Ochida *et al*., 2018). Storage conditions and duration play an important role in tomato quality (Tilahun *et al*., 2017). Packaging can prevent fruits and vegetables from drying out and preserve their quality in terms of taste, texture, and color. The use of packaging aims to protect the fruit from mechanical damage, reduce moisture loss and prevent the germination and spread of microorganisms that can cause damage (Mukama *et al*., 2020). Packaging can delay compositional changes in total soluble solids (TSS), total sugar, sugar reduction, vitamin C, β-carotene, and others (Ochida *et al*., 2018).

Therefore, this study was conducted to determine the effect of storage temperature and the use of polyethylene plastic packaging during storage on both the physicochemical changes and antioxidant properties of tomatoes. Physicochemical changes include color, weight, firmness, and TSS. While antioxidant properties include lycopene content, ascorbic acid, total phenolic content, and free radical scavenging activity (2,2-Diphenyl-1-picrylhydrazyl, DPPH).

MATERIALS AND METHODS

Sample

Two types of tomatoes (*Lycopersicon esculentum* Mill. and cherry tomatoes or *Solanum lycopersicum* var. *Cerasiforme*) were used. Both were purchased from Jaya Grocer, Bangi Gateway, Bangi, Selangor, Malaysia. For uniformity, the level of maturity, color, and size of the samples were ensured to be consistent between the treatment groups.

Study design

A 2×2 factorial design was employed, with two different temperatures (room temperature 25 °C and 4 °C) and two packaging conditions (packed with polyethylene plastic bags and without packaging). Tomatoes were stored in four different conditions: i) packed in polyethylene plastic bags and stored at 25 °C; ii) packed in polyethylene plastic bags and stored at 4 °C; iii) without packaging and stored at 25 °C; iv) without packaging and stored at 4 °C. Samples were examined on days 1, 8, and 15.

Physicocemical changes

Colour

Colour was measured using a colorimeter (Chroma Meter CR-400, Minolta Co. LTD, Japan) with the L*(brightness), a* (redness), and b* (yellowish) systems.

Weight

Weight loss was calculated as the difference between the initial weight and the weight at the measurement time point (days 1, 8, & 15), expressed as % (Tilahun *et al*., 2017).

Firmness

Firmness was measured using a probe-type texture analysis tool (AGS-500NJ, Shimadzu, Japan) (Olveira-Bouzas *et al*., 2021). The resistance to an applied force is expressed in Newton.

TSS

TSS was measured by using a refractometer (TDJ-050 atc, Shenzhen Yago Technology Limited, China) at 0° - 50° (Nemeskeri *et al*., 2019). The value obtained is interpreted as °Brix.

Antioxidant properties

Lycopene content

Based on Tilahun *et al*. (2017), 5 g of homogenized sample was added to a mixture of 5 mL 0.05% (w v) BHT in acetone, 5 mL 95% (v/v) ethanol, and 10.0 mL hexane, then centrifuged at 2500 × *g* for 15 min. A total of 3 mL of deionized water was added and shaken for 5 min, then left at room temperature for 5 min to allow the isolation phase to occur. The absorbance value of hexane i.e., the top layer of the mixture was measured using a spectrophotometer at 503 nm against a blank of hexane solvent. The lycopene content is interpreted as mg/kg of the original weight. The calculation is based on the following equation (Suwanaruang 2016):

$$\text{Lycopene content} = \text{Abs}_{(503\ \text{nm})} \times 137.4\ \text{(constant coefficient)}$$

Ascorbic acid content

A total of 1 g of sample was extracted using 20 mL of 3% (w/v) metaphosphoric acid, then shaken at 300 r.p.m. for 30 min using a shaker. The extract was then centrifuged at 700 × *g* for 10 min. The ascorbic acid content was determined using the 2,6-dichlorophenolindophenol (DCPIP) method described by Nkolisa *et al*. (2019). A total of 1 mL of the extract was mixed with 3 mL of 0.2 mM DCPIP and measured immediately after mixing using a UV spectrophotometer at 525 nm. The value of ascorbic acid obtained was interpreted as mg ascorbic acid/100 g fresh weight of the sample based on the standard curve.

Total Phenolic Content (TPC)

TPC was determined based on Tilahun *et al*. (2017), where 2 g of sample was extracted with 20 mL of 0.05% (v/v) HCl/methanol solution (10:90, v/v), using a homogenizer. A total of 0.2 mL of the extracted sample was mixed with 2 mL of 7% (w / v) sodium carbonate and 0.2 mL of Folin-Ciocalteu reagent. After incubation at room temperature for 90 min, the absorbance was measured using a spectrophotometer at 750 nm. TPC value is expressed as gallic acid equivalent (GAE) in mg / 100 g fresh sample.

Free radical scavenging activity (DPPH)

The free radical scavenging activity was measured using the same extract to determine the TPC (Tilahun *et al*., 2017). DPPH solution with a concentration of 0.15 mM was prepared. DPPH solution (3.9 mL) was mixed with sample extract (0.1 mL). The absorbance was immediately measured (time = min 0, t=0) at 515 nm with a spectrophotometer. Then, the mixture was kept in the dark at room temperature for 30 min and measured (time = min 30, t=30). Methanol was used as the blank. The % of DPPH inhibition is calculated based on the equation: $[(Abs_{t0} - Abs_{t30}) \div Abs_{t0}] \times 100$. Abs_{t0} is the absorbance value at t=0; Abs_{t30} is the absorbance value at t=30.

Statistical analysis

All analyses were performed in three replications. All data obtained were analyzed with analysis of variance (ANOVA) and Tukey test to test for any differences between samples, performed using Minitab software version 17.0 at a confidence level of 95% ($p<0.05$).

RESULTS AND DISCUSSION

Physicocemical changes

Colour Change

Table 1 shows the color changes for tomato and cherry tomatoes during storage, which is an important indicator of the shelf life and level of maturity of tomatoes (Paulsen *et al*. 2019). For both samples, two-way ANOVA showed significant interactions ($p<0.05$) between temperature and packaging factors. It can be observed that the trend of the L* value decreases and the b* value increases in both samples.

Temperature affects the L* and b* values during the storage period of the tomato. The effect of temperature was also significant ($p<0.05$) on the a* value on the 8th day. For cherry tomatoes, temperature affects all the L*, a*, and b* values during the storage period. Al-Dairi *et al*. (2021) found that there was a significant difference between the color brightness value of tomato L* with the storage temperature. Their study also observed an increase in 'redness' and a decrease in 'greenness'. The effect of temperature on the brightness value is supported by Endalew (2020) that observed a reduction in the L* value during storage at 22°C. Tomatoes' color becomes darker due to carotenoid synthesis.

There was a significant effect of packaging on the redness value of tomato (a*) during the storage period. Kumar *et al*. (2020) found that the brightness value of L* did not change much during the storage period in all packaging materials but the redness value of a* increased significantly. In addition, Olveira-Bouzas *et al*. (2021) stated that in ripe tomatoes, the value of a* increased significantly in samples with or without packaging. This indicates that the tomatoes acquire a more concentrated red color throughout the storage process. The increase in a* value is described as the ratio of chlorophyll to carotenoids where chlorophyll degradation occurs during maturation due to carotenoid synthesis. Two major carotenoids in tomatoes including β-carotene and lycopene are closely related to the orange and red colors in tomatoes (van Roy *et al*., 2017). The results obtained are also supported by the study by Jung *et al*. (2019) that observed color change was lower for tomatoes stored with packaging compared to those without packaging.

In this study, temperature and packaging had a significant effect on the b* value. The yellowish color change of tomatoes indicated by the value of b* was influenced by the storage temperature factor (Al-Dairi *et al*., 2021). According to Endalew (2020), the reduction of yellowness (b*) during storage is associated with the development of red color which is indicated by the value of a*.

Weight loss

Table 2 presents the weight loss for both samples. Two-way ANOVA showed both factors had a significant effect ($p<0.05$), except for the cherry tomato on day 15 ($p>0.05$). Tomatoes stored at low temperatures had a relatively low mass loss as the temperature affected the vapor pressure difference which helped in increasing water retention (Kumar *et al*., 2020). Buendia-Moreno *et al*. (2019) stated that the shelf life of tomatoes becomes shorter when the temperature is raised to room temperature during the commercialization period. Fresh weight loss is caused by the processes of respiration and transpiration (Mendes *et al*., 2020). In addition, the findings from this study are also supported by Pathare and Al-Dairi (2021) that reported the % of weight reduction was high for samples that underwent storage for 10 days at room temperature.

There was a significant difference ($p<0.05$) between samples stored with or without packaging. Ashenafi and Tura (2018) reported that unpackaged samples not only showed a rapid increase in mass reduction (%) but also showed the highest percentage of mass reduction at the end of the storage period compared to samples stored with packaging. This is explained by the slow maturation process occurring in tomato samples stored without packaging where this process is indicated by high respiration rates and ethylene production.

Firmness

The firmness of tomato and cherry tomato is shown in Table 2. Two-way ANOVA showed both factors

Table 1. The L*, a*, and b* values of tomato and cherry tomato

Day	Storage Condition	L*	a*	b*
Tomato				
1	With packaging/4 °C	39.02 ± 0.46[b]	19.57 ± 0.47[d]	30.54 ± 0.43[a]
	Without packaging/4 °C	36.38 ± 0.23[c]	25.53 ± 0.97[a]	27.51 ± 0.60[b]
	With packaging/25 °C	41.81 ± 0.51[a]	21.21 ± 0.87[c]	22.48 ± 0.80[c]
	Without packaging/25 °C	37.25 ± 0.20[c]	22.87 ± 0.24[b]	22.04 ± 0.33[c]
8	With packaging/4 °C	36.67 ± 0.21[c]	32.31 ± 0.38[a]	32.10 ± 0.37[b]
	Without packaging/4 °C	40.34 ± 0.17[a]	31.82 ± 0.29[a]	34.81 ± 0.22[a]
	With packaging/25 °C	38.11 ± 0.20[b]	30.77 ± 0.47[a]	26.35 ± 0.11[c]
	Without packaging/25 °C	37.17 ± 0.09[b,c]	28.18 ± 0.76[b]	23.66 ± 0.08[d]
15	With packaging/4 °C	34.44 ± 0.44[c]	26.36 ± 0.18[b]	30.13 ± 0.16[a]
	Without packaging/4 °C	36.46 ± 0.07[b]	27.19 ± 0.37[a,b]	26.55 ± 0.78[b]
	With packaging/25 °C	39.92 ± 0.50[a]	28.32 ± 0.33[a]	26.92 ± 0.33[b]
	Without packaging/25 °C	36.99 ± 0.30[b]	25.9 ± 0.49[b]	25.26 ± 0.17[c]
Cherry tomato				
1	With packaging/4 °C	29.44 ± 0.46[a]	19.68 ± 0.47[b]	21.30 ± 0.43[b]
	Without packaging/4 °C	31.37 ± 0.23[a]	20.34 ± 0.97[a]	24.27 ± 0.60[a]
	With packaging/25 °C	33.39 ± 0.51[a]	18.74 ± 0.87[b]	18.03 ± 0.80[d]
	Without packaging/25 °C	35.29 ± 0.20[a]	21.63 ± 0.24[a]	19.58 ± 0.33[c]
8	With packaging/4 °C	34.09 ± 0.21[b]	25.67 ± 0.36[a]	26.64 ± 0.38[a]
	Without packaging/4 °C	30.59 ± 0.17[c]	20.62 ± 0.29[b]	23.01 ± 0.28[b]
	With packaging/25 °C	36.53 ± 0.20[a]	21.06 ± 0.47[b]	20.15 ± 0.11[c]
	Without packaging/25 °C	33.93 ± 0.09[b]	18.00 ± 0.76[c]	15.67 ± 0.08[d]
15	With packaging/4 °C	32.37 ± 0.44[b]	22.00 ± 0.18[a]	24.94 ± 0.16[a]
	Without packaging/4 °C	24.38 ± 0.07[c]	18.45 ± 0.37[c]	23.37 ± 0.78[b]
	With packaging/25 °C	35.27 ± 0.50[a]	19.52 ± 0.33[b]	22.04 ± 0.33[c]
	Without packaging/25 °C	32.21 ± 0.30[b]	18.54 ± 0.49[c]	18.40 ± 0.17[d]

[a-d]Different alphabet indicates significant differences between groups within the same column for each time point ($p < 0.05$), separately for tomato and cherry tomato samples. Mean ± standard deviation.

Table 2. Weight loss, firmness, and TSS of tomato and cherry tomato

Day	Storage Condition	Weight loss (%)	Firmness (N)	TSS (°Brix)
Tomato				
1	With packaging/4 °C	0.04 ± 0.03[c]	5.04 ± 0.17[a]	6.0 ± 0.0[a]
	Without packaging/4 °C	0.24 ± 0.02[b]	3.86 ± 0.01[b]	4.5 ± 0.0[c]
	With packaging/25 °C	0.09 ± 0.03[c]	5.30 ± 0.20[a]	3.5 ± 0.0[d]
	Without packaging/25 °C	0.49 ± 0.01[a]	2.55 ± 0.07[c]	5.0 ± 0.0[b]
8	With packaging/4 °C	0.19 ± 0.07[c]	3.48 ± 0.29[a]	5.5 ± 0.0[a]
	Without packaging/4 °C	1.31 ± 0.03[b]	2.66 ± 0.05[b]	4.5 ± 0.0[b]
	With packaging/25 °C	0.13 ± 0.04[c]	3.39 ± 0.25[a]	3.5 ± 0.0[c]
	Without packaging/25 °C	4.85 ± 0.03[a]	1.72 ± 0.02[c]	4.5 ± 0.0[b]
15	With packaging/4 °C	0.29 ± 0.03[d]	3.04 ± 0.01[a]	5.0 ± 0.0[a]
	Without packaging/4 °C	16.09 ± 0.04[c]	2.09 ± 0.01[b]	4.5 ± 0.0[b]
	With packaging/25 °C	32.30 ± 0.03[b]	3.03 ± 0.03[a]	3.5 ± 0.0[c]
	Without packaging/25 °C	36.83 ± 0.00[a]	1.02 ± 0.01[c]	3.0 ± 0.0[d]
Cherry tomato				
1	With packaging/4 °C	5.10 ± 0.68[a]	2.75 ± 0.02[a]	9.0 ± 0.0[b]
	Without packaging/4 °C	1.50 ± 0.65[b]	2.42 ± 0.07[b]	10.5 ± 0.0[a]
	With packaging/25 °C	2.24 ± 0.56[b]	2.314 ± 0.00[c]	8.0 ± 0.0[c]
	Without packaging/25 °C	1.27 ± 0.00[b]	2.13 ± 0.01[d]	8.0 ± 0.0[c]
8	With packaging/4 °C	13.34 ± 0.70[b]	2.56 ± 0.03[a]	9.0 ± 0.0[b]
	Without packaging/4 °C	7.23 ± 1.42[c]	1.62 ± 0.04[c]	10.0 ± 0.0[a]
	With packaging/25 °C	28.16 ± 0.00[a]	1.94 ± 0.03[b]	7.5 ± 0.0[d]
	Without packaging/25 °C	12.70 ± 0.69[b]	1.37 ± 0.03[d]	8.0 ± 0.0[c]
15	With packaging/4 °C	15.15 ± 0.00[d]	2.35 ± 0.02[a]	8.0 ± 0.0[b]
	Without packaging/4 °C	21.90 ± 0.56[c]	1.26 ± 0.05[c]	9.0 ± 0.0[a]
	With packaging/25 °C	35.29 ± 0.64[b]	1.75 ± 0.03[b]	6.0 ± 0.0[d]
	Without packaging/25 °C	41.09 ± 1.34[a]	1.07 ± 0.01[d]	7.5 ± 0.0[c]

[a-d]Different alphabet indicates significant differences between groups within the same column for each time point ($p<0.05$), separately for tomato and cherry tomato samples. Mean ± standard deviation.

had a significant effect ($p<0.05$) on the firmness throughout the experiment. The results obtained show similarities with the results of the findings in the study of Buendía-Moreno *et al*. (2019) with the reduction in firmness being higher in samples stored at 25 °C compared to 8 °C. Olveira-Bouzas *et al*. (2021) in their study observed packaging significantly reduce the firmness of ripe tomato. This is associated with high water vapor condensation in the packaging which in turn causes the fruit to become soft. Nevertheless, a study by Paulsen *et al*. (2019) on the other hand stated that a higher reduction in firmness was shown by unpackaged tomatoes. This is described as a greater reduction in fruit mass due to water loss directly affecting tissue structure. Decreased firmness is associated with enzyme activity. Throughout the maturation process of tomato fruit, there is softening of the pulp due to the degradation of peptic material (Mendes *et al*. 2020). Moreover, enzymatic decomposition of pectin occurs leading to softening (Buendía-Moreno *et al*., 2019).

Significant differences observed between samples stored with or without packaging at each time point are supported by a study by Paulsen *et al*. (2019). In their study, tomatoes packed in polyethylene were able to maintain the firmness value in the first week and showed a significant decrease in the second week. Nevertheless, the firmness remained unchanged in the last week of storage. In parallel, Jung *et al*. (2019) stated that polyethylene plastic exerts a protective effect on tomato firmness.

TSS content

There were significant effects ($p>0.05$) of temperature and packaging for all samples during the storage period (Table 2). This is supported by a study conducted by Olveira-Bouzas *et al*. (2021) noted that there was a significant increase in TSS values after 7 days of storage in tomatoes stored with or without packaging. Pathare and Al-Dairi (2021) reported that TSS was influenced by storage temperature. Storage of tomatoes at room temperature (22 °C) increased the TSS content of tomatoes associated with the conversion of complex sugars (starches) to simpler sugars such as fructose through active enzymatic reactions (Pathare *et al*., 2020). Asgar (2020) stated that a suitable packaging material for packing fresh tomatoes is polyethylene because it is flexible, and has low water and water vapor permeability.

Antioxidant Properties

Lycopene Content

Table 3 shows the changes in lycopene content, with an increasing trend for both samples throughout the experiment. Two-way ANOVA indicated both factors had a significant effect ($p<0.05$), except for the tomato on day 8 ($p>0.05$). The findings of the study are supported by Martínez-Hernández *et al*. (2016) where lycopene degradation was seen to increase in tandem with increasing storage temperature. Storage could lead to lycopene loss in tomatoes, associated with several variables including temperature, light, oxygen, and water activity (Shi *et al*., 2002). The temperature has a significant impact on the lycopene loss during storage, with increasing storage temperatures significantly increasing degradation. The degradation mainly occurs due to oxidation without isomerization in the temperature between 25 to 50 °C (Hacket *et al*., 2004).

This study found that packaged samples recorded higher values ($p<0.05$) than unpackaged ones. Dandago *et al*. (2019) found that packaging during post-harvest storage had a significant effect on lycopene content on days 6 and 24. In the same study, lycopene content in tomatoes packaged in sealed polyethylene bags was observed to increase and subsequently showed a decrease throughout the storage period. A study by Olveira-Bouzas *et al*. (2021) stated that there was lycopene biosynthesis observed in packaged tomatoes up to 7 days of storage, while lycopene content was recorded to decrease with storage time in unpackaged tomatoes. Moreover, a study by Feizi *et al*. (2020) also found that storage with thin or thick polyethylene packaging bags at ambient temperature recorded a higher lycopene content compared to other storage conditions. Nevertheless, the effect of packaging on lycopene is different based on the study by Paulsen *et al*. (2019) where the increase in lycopene content was highest in unpackaged tomatoes. This is also associated with the stage of maturity of tomatoes. At a higher stage of maturity, the lycopene content in the fruit is also higher.

Ascorbic acid content

Overall, two-way ANOVA showed significant effects and interactions ($p<0.05$) between the two factors on ascorbic acid content (Table 3) only on day 15, in the cherry tomato sample alone. Asgar (2020) stated that samples stored at room temperature showed the lowest vitamin C content and showed significant differences with the other three temperatures namely 5 °C, 10 °C, and 15 °C. Vitamin C is characterized as an easily oxidized component because it contained a hydroxy (OH) functional group that is highly reactive to the presence of a hydroxy group oxidizer. Therefore, the oxidation process of vitamin C can be inhibited when in low temperatures. The significant effect of packaging on the ascorbic acid content of tomatoes is also supported by Kumar *et al*. (2020) where a storage temperature of 10 °C in the presence

Table 3. Lycopene content, ascorbic acid content, TPC, and free radical scavenging activity (DPPH) of tomato and cherry tomato

Day	Storage Condition	Lycopene (mg/kg)	Ascorbic Acid (mg/100 g)	TPC (mg/100 g)	Free radical scavenging activity (DPPH) %
Tomato					
1	With packaging/4 °C	11.29 ± 0.04[a]	0.22 ± 0.04[a]	3.07 ± 0.01[a]	20.84 ± 0.23[b]
	Without packaging/4 °C	8.69 ± 0.19[c]	0.18 ± 0.01[a]	2.90 ± 0.00[a]	25.46 ± 0.20[a]
	With packaging/25 °C	8.72 ± 0.14[c]	0.18 ± 0.02[a]	2.24 ± 0.04[a]	19.35 ± 0.20[c]
	Without packaging/25 °C	9.24 ± 0.18[b]	0.18 ± 0.01[a]	2.89 ± 0.00[a]	6.15 ± 0.20[d]
8	With packaging/4 °C	17.33 ± 0.10[a]	0.22 ± 0.02[a]	12.38 ± 0.00[a]	33.29 ± 0.43[b]
	Without packaging/4 °C	17.49 ± 0.26[a]	0.20 ± 0.00[a]	11.31 ± 0.00[a]	33.59 ± 0.56[b]
	With packaging/25 °C	15.45 ± 0.25[b]	0.22 ± 0.02[a]	6.25 ± 0.00[b]	24.04 ± 0.06[c]
	Without packaging/25 °C	15.07 ± 0.13[b]	0.20 ± 0.00[a]	4.37 ± 0.00[b]	36.28 ± 0.53[a]
15	With packaging/4 °C	44.42 ± 0.31[a]	0.40 ± 0.02[b]	22.96 ± 0.03[a]	97.17 ± 0.10[a]
	Without packaging/4 °C	34.59 ± 0.85[b]	0.42 ± 0.01[b]	20.44 ± 0.04[b]	97.11 ± 0.22[a]
	With packaging/25 °C	20.96 ± 0.21[c]	0.53 ± 0.05[a]	9.42 ± 0.04[c]	97.05 ± 0.205[a]
	Without packaging/25 °C	17.51 ± 0.06[d]	0.61 ± 0.01[a]	11.48 ± 0.07[c]	96.74 ± 0.20[a]
Cherry tomato					
1	With packaging/4 °C	12.53 ± 0.14[a]	0.20 ± 0.01[a]	3.59 ± 0.01[a]	27.14 ± 0.24[c]
	Without packaging/4 °C	11.35 ± 0.10[b]	0.20 ± 0.01[a]	3.42 ± 0.00[a]	28.78 ± 0.07[b]
	With packaging/25 °C	13.31 ± 0.20[a]	0.19 ± 0.01[a]	3.34 ± 0.02[a]	22.31 ± 0.16[d]
	Without packaging/25 °C	9.95 ± 0.25[a]	0.20 ± 0.01[a]	2.62 ± 0.11[a]	29.59 ± 0.25[a]
8	With packaging/4 °C	21.36 ± 0.38[a]	0.17 ± 0.01[b]	10.54 ± 0.01[a]	33.18 ± 0.24[b]
	Without packaging/4 °C	15.87 ± 0.25[c]	0.21 ± 0.01[a]	10.39 ± 0.01[a]	26.47 ± 0.13[d]
	With packaging/25 °C	17.15 ± 0.15[b]	0.18 ± 0.01[b]	5.21 ± 0.00[c]	29.11 ± 0.39[c]
	Without packaging/25 °C	14.28 ± 0.16[d]	0.20 ± 0.01[a]	6.72 ± 0.05[b]	39.49 ± 0.20[a]
15	With packaging/4 °C	23.44 ± 0.24[a]	1.00 ± 0.08[a]	20.05 ± 0.03[a]	97.25 ± 0.20[a]
	Without packaging/4 °C	23.90 ± 0.63[a]	0.80 ± 0.01[b]	19.19 ± 0.03[a]	97.25 ± 0.06[a]
	With packaging/25 °C	18.47 ± 0.09[b]	0.60 ± 0.02[c]	10.90 ± 0.06[b]	97.23 ± 0.08[a]
	Without packaging/25 °C	15.15 ± 0.05[c]	0.55 ± 0.01[c]	9.50 ± 0.01[b]	96.86 ± 0.48[a]

[a-d]Different alphabet indicates significant differences between groups within the same column for each time point ($p<0.05$), separately for tomato and cherry tomato samples. Mean ± standard deviation.

of packaging helps inhibit tomato ripening which in turn reduces the rate of acid decline in the fruit. Babatola and Ibukunolu (2020) observed a significant difference in the ascorbic acid content of tomatoes stored on open shelves and in the refrigerator. The conversion rate of organic acids in samples without packaging was higher than in packaged samples, associated with an increased respiration rate during storage (Saberi *et al*., 2018).

TPC

Two-way ANOVA showed significant effects and interactions ($p<0.05$) between the two factors on TPC (Table 3) only on day 8 in cherry tomato. The temperature factor had a significant effect on TPC on days 8 and 15.

Esua *et al*. (2019) noted that certain cooling temperatures typically generate physiological stresses that cause an increase in several enzymes such as phenylalanine ammonia-lyase (PAL) that are believed to be involved in the synthesis of tomato phenolic components. Sharma *et al*. (2019) found that the increase in phenolic content was observed more significantly at a temperature of 10°C. This is explained by the occurrence of an adaptive reaction to cold temperatures in the production of polyphenols during post-harvest storage. Some phenolic compounds are typically accumulated in plant cells due to stress at cold temperatures as they contribute to the homeostasis of reactive oxygen species (ROS) as well as an increase in cell wall thickness to prevent lipid oxidation and cell damage. In addition, Patanè *et al*. (2019) stated that tomatoes grown in open conditions at a temperature of almost 30 to 32 °C during the maturation process showed an increase in the accumulation of phenolic compounds.

There were no significant differences ($p>0.05$) were observed in samples stored with or without packaging on days 1 and 15. In agreement, Patanè *et al*. (2019) found that overall, the packaging did not affect the phenolic content of tomatoes during storage. A study by Khalid *et al*. (2020) on strawberries also showed that there was no significant effect on samples stored without or with polyethylene packaging. Olveira-Bouzas *et al*. (2021) also found that no significant differences were observed between unpackaged and packaged tomatoes throughout the storage process.

Free radical scavenging activity (DPPH)

The free radical scavenging activity (DPPH) is shown in Table 3. Two-way ANOVA analysis showed that both temperature and packaging factors had significant effects and interactions for days 1 and 8. Nkolisa *et al*. (2019) observed significant differences in the free radical scavenging activity (DPPH) of tomatoes stored at cold temperatures and room temperature. Temperature is an important factor that can influence the process of photosynthesis of plants which also affects the quality of the synthesis of certain nutrients, such as sugars, organic acids, and antioxidants (Firdous 2021). Generally, the optimum temperature is 21 to 25 °C and only high temperatures above 38 °C can inhibit the production of lycopene, TSS, and carotenoids as well as the activity of antioxidants in tomatoes (Wonprasaid & Machikowa 2021). No significant differences ($p>0.05$) were observed in samples stored with or without packaging on the 15th day of storage. These findings are supported by a study by Paulsen *et al*. (2019) stated that tomatoes showed a decrease in antioxidant capacity during the first week of storage, regardless of packaging conditions but no significant differences were shown between samples with packaging or without packaging at the end of the storage period.

CONCLUSION

In conclusion, both temperature and packaging factors play an important role in maintaining the physicochemical and antioxidant properties of both tomatoes and cherry tomatoes. Storage at a low temperature (4 °C) in the presence of packaging maintained physicochemical properties such as weight and firmness in both types of tomatoes throughout the storage period. In addition, the storage condition helped maintain lycopene content and increased free radical scavenging activity (DPPH) in both samples throughout the storage period.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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