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Impacts of some eco-friendly methods on the storage life of tomato fruits

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ABSTRACT

The objective of current research was to explore the influence of several eco-friendly techniques, including modified atmosphere packaging (MAP), edible coating (EC), heat treatment and edible coating enriched with centaury oil (EO), on the postharvest storage of tomato fruit. Tomatoes (*Solanum lycopersicum*) cv. Newton were harvested red ripe and used in this experiment. Experimental studies were established on 5th February 2023. A total of 8 treatments were tested. They were: 1) control, 2) MAP, 3) MAP+EC, 4) EC, 5) MAP+EC+EO, 6) EC+EO, 7) hot air and 8) MAP+hot air. The experiments were continued for 30 days and the measurement points time intervals were defined as 5, 10, 15, 20, 25, and 30 days (six different measurements points), 384 fruits in total were utilized in the storage studies and 8 extra fruits were used at the start as a control to identify the fruit's initial qualities. The fruits were kept for 30 days at 6 to 8 °C and 90 to 95 % relative humidity. According to the study's findings, each treatment had a significant impact on the fruit's decay incidence, weight loss, vitamin C content fruit firmness, chilling damage and SSC. The study found that all treatments significantly improved the quality of the tomato fruits, except for SSC. The best results were obtained from the MAP+EC and MAP+EC+EO treatments. Tomato fruits can be stored at a temperature range of 6 to 8°C for up to 20 days, demonstrating the effectiveness of the treatments.

1. Introduction

One of the world's most significant fruit plants is the tomato (*Solanum lycopersicum*). Globally, roughly 180 million tons of tomato are cultivated yearly which has expanded by 165% over the past 20 years and is anticipated to keep growing in the upcoming years (Wyngaard and Kissinger 2022).

As a healthy component of a balanced diet, tomatoes are simple to incorporate and contain a variety of chemicals that are beneficial to human health (Martí et al. 2016). There has been an increase in the past ten years in consumer knowledge of the health benefits of foods and their involvement in avoiding a range of chronic illnesses and dysfunctions (Dhandevi and Jeewon 2015).

According to Cherono et al. (2018) the overall quality of fresh products, such as tomatoes, is substantially connected with the temperature of storage and storage period. Tomato flavor, firmness and color can all be significantly impacted by storage temperature. Due to their high moisture content, tomatoes have a 48-hour shelf life and are a perishable crop (Muhammad et al. 2011).

Due to their potential harm to human health, agrochemicals are becoming less accepted on a global scale (Sharma et al. 2009). As a result, studies aimed at finding alternatives to agrochemicals are extremely important.

In order to ensure product safety and increase the shelf life of fruits and vegetables wrapped in polymeric films, modified atmosphere packaging (MAP) has been utilized extensively along with refrigeration (Abadias et al. 2012).

Application of coatings that are edible either alone or in combination with essential oils, plant extracts, and active metabolites, is one of the effective postharvest handling procedures used to protect postharvest fruit quality (Chen et al. 2019). Edible films and covers can be made from a variety of materials. The most often utilized are polysaccharides (starches cellulose, derivatives, microbial gums & or vegetable etc.), proteins (gluten, zein and gelatin etc.) & lipids (lipid derivatives and waxes) (Fakhouri et al. 2007).

Essential oils have recently attracted a lot of attention as potential substitutes for chemical preservatives (Mastromatteo et al. 2011). Lemongrass essential oil shows antibacterial action towards a wide variety of microbes, especially molds, yeast and both gram positive & gram-negative bacteria (Naik et al. 2010).

According to Liu heat treatment can reduce disease symptoms, inactivate or completely kill germinating spores and delay the growth of the pathogen's germ tubes (Liu et al. 2012).

The objective of this study was to investigate the impact of edible coating (EC), centaury oil, MAP, heat treatment application and their combined effects on tomato post-harvest preservation. The findings of this study indicated that all the applied treatments had a noteworthy influence on various parameters including fruit firmness, fruit weight, decay incidence, chilling injury & vitamin C content. However, the effects on soluble solids content (SSC) and titratable acidity (TA) were found to be negligible.

2. Materials and methods

2.1. Materials

"Newton" cultivar tomatoes (*Solanum lycopersicum*) were used in this study. Tomato fruits were collected from Yedidalga Lefke city in the Turkish Republic of Northern Cyprus on 5 February 2023. The fruits were kept throughout harvest and brought to the European University of Lefke, Research and Implementation Farm within two hours after harvest (approximately) under controlled conditions (10 C). Tomato fruits were picked for this research when they were red ripe or red matured. The other materials used in this study were modified atmosphere packaging (MAP) bags, centaury oil (EO), starch, glycerol, alcohol, heat treatment machine, weighting scale, refractometer, penetrometer, plastic shell packaging, and a cold room. All 100% of the Vesile plant centaury oil (Centaurium erythraea Rafn) used during this study was obtained from the ilksen pharmacy in the Turkish Republic of Northern Cyprus, Gemikongi. The modified atmosphere packaging (MAP) materials were ordered online from the fresh plus packaging company Türkiye with a brand of Fresh Plus map. The plastic shell for tomatoes packaging was received from Nicosia. The remaining above mentioned materials or equipment which were used were provided by the European University of Lefke research and implementation farm.

2.2. Experimental methodology

This research experiment was composed of eight distinct treatments and studies lasted up to 30 days. It was decided that there would be six separate measuring points: 5, 10, 15, 20, 25, and 30 days. For each experiment (#8) and each measurement point (#6), four replications (each with 12 fruits) were employed. Two fruits from each replication (a total of 8) for each treatment were taken out of the storage rooms at each measurement point for quality analysis. Thus, a total of 384 (8 treatments * 4 replication * 12 fruits in each replication) fruits were used in the storage trials while an additional 8 fruits served as a control at the start of the research to assess the fruit's initial quality.

A solution of diluted maize starch (2% w/v) & glycerol (0.5% v/v) was boiled at 90-95°C for 30 minutes in distilled water to create the edible coating. The same process was used to prepare an edible coating supplemented with centaury oil (0.5%) dissolved in ethyl alcohol (70%) 2:1 v/v.

A total of eight treatments were tested. These were : 1) control, 2) MAP, 3) MAP+EC, 4) EC, 5) MAP+EC+EO, 6) EC+EO, 7) hot air and 8) MAP+hot air. The fruits were divided into eight groups (number of treatments), each having 48 (12*4) fruits. The tomato fruits were dipped in the aforementioned treatments for 1 minute. After dipping, the fruits were air-dried for two hours. The application of hot air (45°C) was done by supplying a 30-minute heat treatment. A detailed explanation of the treatments is given in Table 1.

Next, the weights of each fruit were calculated and noted for subsequent analysis. After that, the fruits were organized neatly into tomato-shaped plastic containers and stored at 6°C to 8°C with 90-95% relative humidity.

2.3. Data collection

Then, at each measurement point, the new (final) weights of each fruit were recorded and used for the calculation of the (%) weight loss. A digital scale (0.01 g) was utilized for the determination of fruit weights. The percentage of weight reduction was calculated using the usual ratio approach.

The number of decayed fruits was noted in each replication of all treatments, Because of high levels of water activity, fresh tomatoes & tomato-based products are extremely sensitive to yeast and fungus development, including *Fusarium*, *Aspergillus niger* & *Penicillium* (Elahi et al. 2021).

Using a hand penetrometer, the fruit firmness (kg cm^{-2}) of each tomato fruit was determined and noted. Each fruit's firmness was measured at one location within the fruit's core and the average was utilized in the calculations.

To determine the soluble solids concentration, 1 fruit from each replication of the same treatment (4 tomatoes) were pressed and the juice extracted and put on a hand refractometer to measure the SSC of tomato fruits.

The vitamin C (VC) content was assessed by titration with iodine solution (Skinner 1997). The strong antioxidant ability of VC for preventing the reaction of iodine with starch was used to determine the VC content of the samples. Therefore, first of all the necessary iodine concentration for oxidization of a known amount of ascorbic acid was calculated as a standard solution (calibration). Then, the amount of iodine needed for the oxidization of an unknown (tomato) sample was determined. To do it, 10 ml of tomato juice, 5 ml of starch solution and 85 ml of pure water were mixed in a clean cup. Tincture of iodine was added into the solution drop by drop and stirred gently after each drop (same procedure for calibration). It was continued until there was a constant blue/black color and the number of drops required for titration was noted. The required amount of iodine for titration was then used in the formula below for estimating vitamin C mass in mg per g^{-1}:

$$\text{VC of sample (mg ml}^{-1}\text{)} = \left(\frac{\text{number of drops}}{\text{10 (volume of sample)}}\right) \times \text{calibration}$$

The fruit of tomatoes is highly capable of suffering chilling injury (CI), a postharvest physiological problem brought on by insufficient storage temperatures. Symptoms of CI include sunken spots on the fruit (blemishes), disease susceptibility and slowing of ripening & color development. Tomato fruit was evaluated for chilling damage using a 0-4 scale. By comparing the Cl area to the total area, five grades of Cl symptoms were created.

- 0: no Cl symptom:
- 1: slight damage (<25%);
- 2: moderate damage (25% to 50%)
- 3: moderately severe damage (50% to 75%).
- 4: severe damage (>75%)

The above-described scale was used in the formula given below to determine the chilling injury (CI) incidence of each treatment.

$$CI = \{[(1 \times N1) + (2 \times N2) + (3 \times N3) + (4 \times N4)] / (4 \times N)\}.$$

N stands for the total amount of fruit that was measured, while N1, N2, N3 and N4 denote the numbers of fruit that showed various degrees of chilling harm.

Table 1. Detailed explanation of the eight treatments of current study

Number	Treatment	Definition
1	Control	A control is a group of tomatoes that did not receive the treatment being tested.
2	MAP	Modified atmosphere package ordered online from fresh plus packaging company Turkey with a brand of Fresh Plus map.
3	MAP+EC	The treatment 1 and 4 were combined.
4	EC	The edible coating contains corn starch, glycerol, and water. To make the coating, the corn starch (2% w/v) and glycerol (0.5% v/v) are added to distilled water (2.5 liter) and boiled for about 20 minutes until the mixture reaches 100 degrees Celsius. This high temperature helps to dissolve the corn starch and create a uniform, smooth texture. The resulting mixture can be used to provide a barrier on the surface of food goods, preventing moisture loss, microbial contamination & other types of degradation.
5	MAP+EC+EO	This treatment involves a combination of MAP and EC with oil to make tomato fruits last longer on the shelf. The edible coating is made from corn starch (2% w/v) & glycerol (0.5% v/v), which are dissolved in distilled water (2.5 liter) along with centaury oil (0.5%) and alcohol (1%). Centaury oil is a natural oil derived from the centaury plant, which has been used for its medicinal properties and also has potential as an antimicrobial agent.
6	EC+EO	These two were combined (corn starch 2% w/v) and glycerol (0.5% v/v) in distilled water with the addition of centaury oil (0.5%) and alcohol (1%) boiled for about 20 minutes until 100 centigrade. Both coatings can be used to protect food goods against oxidation, moisture loss, & microbiological contamination by creating a barrier on their surface.
7	Hot air	In this treatment, the tomato fruit is exposed to hot air (45°C) for a period of up to 30 minutes using a hot air machine.
8	MAP+ hot air	MAP + hot air. The treatment 2 and 7 were combined.

2.4. Statistical analysis

Microsoft Office Excel 2007 was used to compute the means & standard deviations for every treatment based on the raw data. The graphs below were created using the results. To find any statistically significant differences, the experiment's raw data were then put through an analysis of variance (an ANOVA) in SPSS 22.0. Mean separations had been examined by using the Tukey's HSD test at $P\leq0.05$.

3. Results and Discussions

3.1. Effect of treatment on the weight loss

One of the most important determinants of the postharvest quality of fresh fruits is weight loss because it has an impact on the products' weight, appearance, texture and general acceptability, which in response influences consumers' purchasing decisions (Sabir et al. 2004). In all treatments weight loss increased as storage time passed. The control treatment resulted in the greatest weight reduction, but the modified atmosphere package with edible coating (MAP+EC) caused the least weight loss. An absolute maximum gain was seen with the control treatment (see Figure 1). Comparatively to the control, treated fruits lost relatively little weight, demonstrating that the modified atmosphere package with edible coating (MAP+EC) had an impact on reducing tomato fruit weight loss. Weight loss rose across all fruit groups for the 30 days of storage for tomato fruits, while some treatments were successful in lowering the weight loss. (Figure 1). After 25 days of storage, a few other treatments (EC+EO, EC, MAP+hot air) were likewise ineffective. The control treatment experienced the greatest weight loss during storage (11.5%) and the fruits treated with MAP combined with edible coating (MAP+EC) showed the lowest weight loss of 4.1%. The similar trend was continued till the end MAP+EC 4.1%, MAP+EC+EO 4.3%, MAP 5.3%, MAP+hot air 7.6%, EC+EO 8.2%, hot air 8.8%, EC 8.2% and control 11.5%. Additionally, successful at preserving & reducing weight loss MAP+EC+EO was used to maintain the quality of the tomato fruit. These findings make it clear that MAP+EC, EC combined with and without oil (MAP+EC+EO) & MAP are the most effective treatments for slowing weight loss.

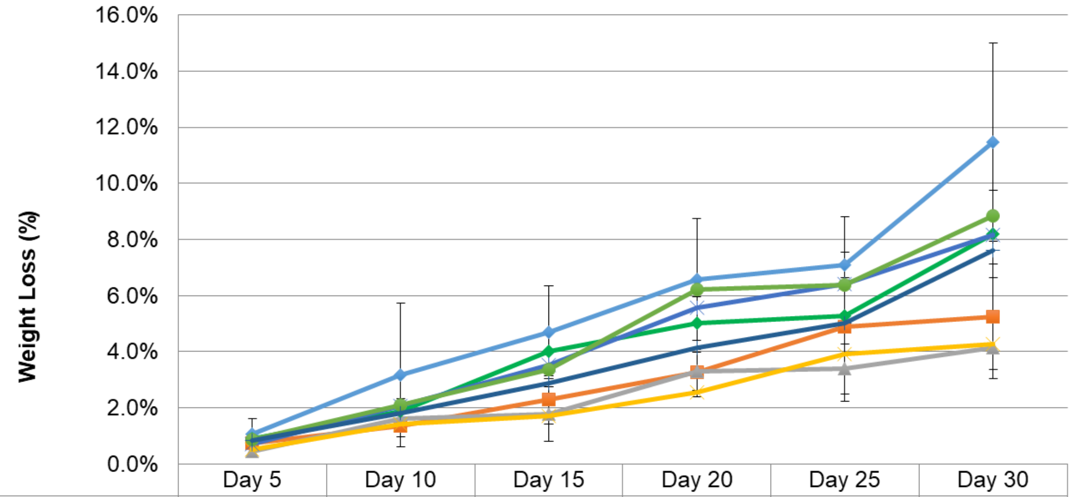
According to Kibar et al. (2018) his research results indicate that MAP and chitosan coating can significantly keep the quality of tomatoes high & reduce weight loss during storage. Olawuyi et al. (2019) also suggested that the combined treatment may significantly decrease weight loss & maintain the quality of cucumber during storage. Similar results were noted by Mangaraj and Goswami (2009).

3.2. Effects of treatments on the Decay Incidence

Tomatoes are particularly perishable by nature due to the large amount of free & bound water that is available for the growth of different microbes. Tomato fruits were safe in all groups for the first ten days of storage. After 25 days of storage, however, both edible coating and the control treatment's fruit showed high rot. The control fruits showed the greatest DI values at 75%, edible coating at 62% and EC+E0 at 50% (see Figure 2). As expected, the highest impact was noted from the hot air & MAP+hot air at 15% and was followed by the MAP+EC+E0 with 22.5%, MAP+EC with 25% and MAP with 27.5%. Similar results were previously mentioned by multiple researchers. Fallik et al. (1999) developed an innovative fast hot water treatment to enhance the quality of sweet pepper storage. Wan et al. (2020) reported similar findings on Newhall navel oranges and their findings suggested that the period of heat treatment plays a critical role in maximizing preventive measures of fruit rot and weight loss.

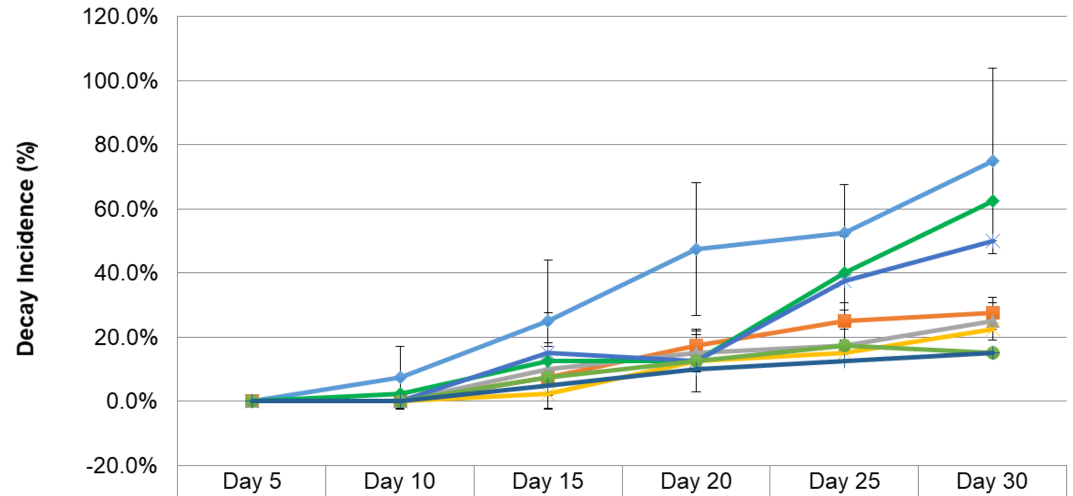
3.3. Effects of treatments on the fruit firmness

During storage, there was a trend toward lessening fruit firmness in tomato fruits. The initial fruit firmness of the control fruits, which was 0.45 kg cm^{-2} at the start of storage, decreased to 0.28 kg cm^{-2} after 30 days (Figure 3). Fruits kept in MAP+EC were reported to have a 0.26 kg cm^{-2} fruit firmness at the same time. The most effective treatment for maintaining fruit firmness appears to be the combination of EC with MAP+EC treatment. This treatment shows the most positive effect on fruit firmness in comparison to the alternative treatment with the most significant difference observed on Day 10 and beyond. The MAP & EC treatment also has a positive effect on fruit firmness. The other treatments, including, EC+EO, hot air and MAP+hot air, have



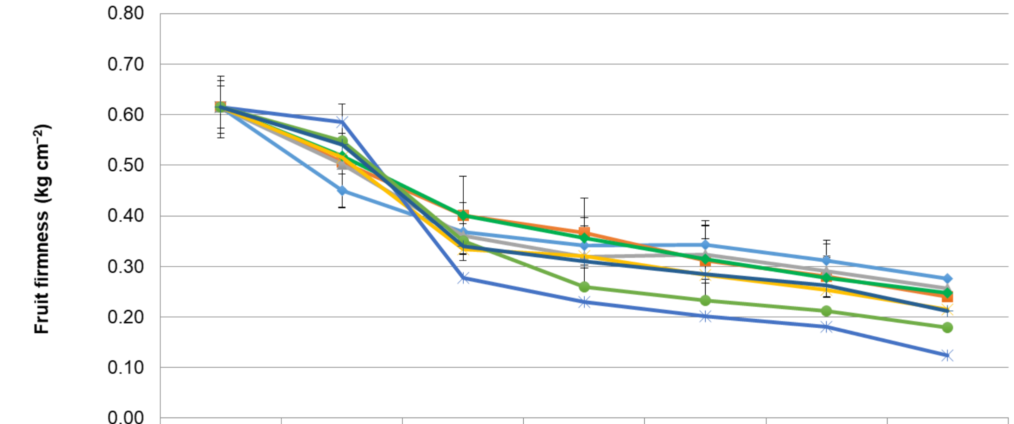
	Day 5	Day 10	Day 15	Day 20	Day 25	Day 30
Control	1.1% a	3.2% a	4.7% a	6.6% a	7.1% a	11.5%a
MAP	0.7% ab	1.4% b	2.3% cde	3.3% bc	4.9% abc	5.3% cd
MAP+EC	0.5% b	1.6% ab	1.8% de	3.3% bc	3.4% c	4.1% d
EC	0.9% ab	1.9% ab	4.0% ab	5.0% abc	5.3% abc	8.2% abc
MAP+EC+EO	0.5% b	1.4% b	1.7% e	2.6% c	3.9% bc	4.3% d
EC+EO	0.7% ab	2.1% ab	3.5% abc	5.6% ab	6.4% ab	8.2% abc
Hot Air	0.9% ab	2.1% ab	3.4% bcd	6.2% a	6.4% ab	8.8% ab
MAP+Hot Air	0.8% ab	1.8% ab	2.9% cde	4.1% abc	5.0% abc	7.6% bcd

Figure 1. Weight loss of the tomato fruits throughout the duration of 30 days of storage as influenced by the various treatments. (The means of various treatments are compared independently at each measurement point using the letters in the table below the figure. According to Tukey's HSD, different letters are employed to indicate scientific differences at the $P \leq 0.05$ level.



	Day 5	Day 10	Day 15	Day 20	Day 25	Day 30
Control	0.0% a	7.5% a	25.0% a	47.5% a	52.5% a	75.0% a
MAP	0.0% a	0.0% a	7.5% a	17.5% b	25.0% bc	27.5% bc
MAP+EC	0.0% a	0.0% a	10.0% a	15.0% b	17.5% c	25.0% bc
EC	0.0% a	2.5% a	12.5% a	12.5% b	40.0% ab	62.5% a
MAP+EC+EO	0.0% a	0.0% a	2.5% a	12.5% b	15.0% c	22.5% bc
EC+EO	0.0% a	0.0% a	15.0% a	12.5% b	37.5% ab	50.0% ab
Hot Air	0.0% a	0.0% a	7.5% a	12.5% b	17.5% c	15.0% c
MAP+Hot Air	0.0% a	0.0% a	5.0% a	10.0% b	12.5% c	15.0% c

Figure 2. Decay incident of the tomato fruits throughout the duration of 30 days of storage as influenced by the various treatments. (The means of various treatments are compared independently at each measurement point using the letters in the table below the figure. According to Tukey's HSD, different letters are employed to indicate scientific differences at the $P \leq 0.05$ level.



	Day 0	Day 5	Day 10	Day 15	Day 20	Day 25	Day 30
Control	0.62 a	0.45 c	0.37 ab	0.34 ab	0.34 a	0.31 a	0.28 a
MAP	0.62 a	0.51 abc	0.40 a	0.37 a	0.31 a	0.28 ab	0.24 ab
MAP+EC	0.62 a	0.50 bc	0.36 ab	0.32 abc	0.32 c	0.29 ab	0.26 a
EC	0.62 a	0.52 abc	0.40 a	0.36 ab	0.32 a	0.28 ab	0.25 ab
MAP+EC+EO	0.62 a	0.52 abc	0.33 ab	0.32 abc	0.28 ab	0.25 abc	0.22 ab
EC+EO	0.62 a	0.59 a	0.28 b	0.23 c	0.20 c	0.18 c	0.12 c
Hot Air	0.62 a	0.55 ab	0.35 ab	0.26 bc	0.23 bc	0.21 bc	0.18 bc
MAP+Hot Air	0.62 a	0.54 ab	0.34 ab	0.31 abc	0.29 ab	0.26 ab	0.21 ab

Figure 3. Fruit firmness of the tomato fruits throughout the duration of 30 days of storages influenced by the various treatments. (The means of various treatments are compared independently at each measurement point using the letters in the table below the figure. According to Tukey's HSD, different letters are employed to indicate scientific differences at the $P\leq0.05$ level.

either a negative or slightly positive impact on fruit firmness compared to the control group. The ripening process is inversely correlated with the tomatoes' firmness. (Wakabayashi et al. 2000). Similar results were previously suggested by Kahramanoğlu and Usanmaz (2019) on cucumber fruit, their results suggested that cucumber fruit firmness can be preserved in MAP bags for twenty days (20d) at 4.5 ± 0.5°C & 95% RH. A similar result was noted by Wei et al. (2021) on mango fruits, their result suggested that the MAP compound treatment improved mangoes' ability to retain their commercial qualities, followed by the application of the edible coating compound treatment.

3.4. *Effects of treatments on the soluble solids concentration*

The results indicated that the treatments had no statistically significant impact on tomato fruit SSC, however in some treatments, SSC means were found to differ significantly over the period of storage (Figure 4). Especially MAP+EC treatment resulted in a reduced soluble solids concentration from 0 to 5 days, but after that, the concentration remained relatively stable and did not decrease as much as in the other treatments. The concentration even increased slightly between days 25 and 30. This demonstrates that the MAP+EC treatment helped to maintain the fruit quality of the tomato and minimize the breakdown of sugars. Overall, the other treatments (MAP, EC, EC+EO, hot air, and MAP+hot air) also had varying affects on the concentration of soluble solids of the tomato fruits over time, but none of them appeared to be as effective as the MAP+EC treatment in preserving the fruit's level of quality.

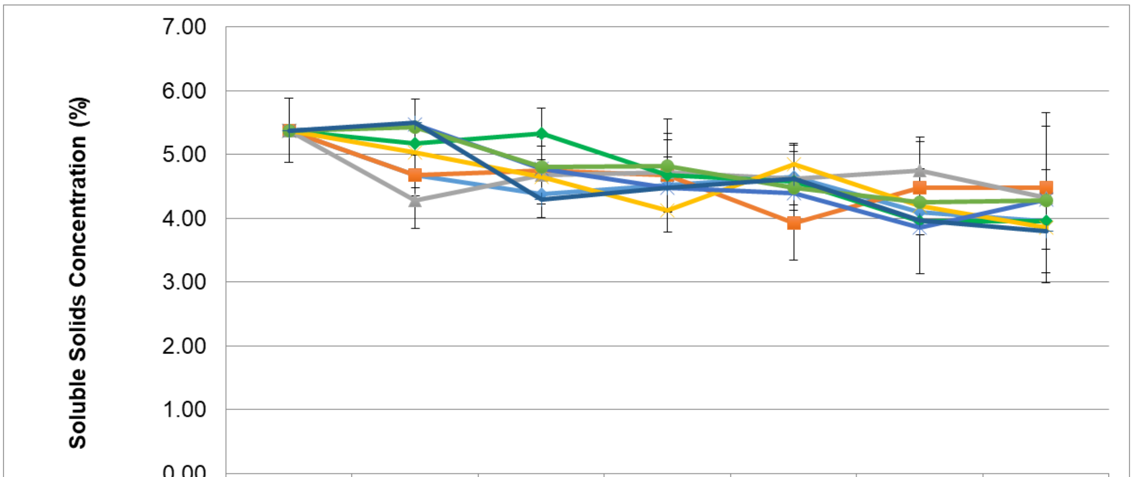
Similarly, Öztürk and Ağlar (2019) reported that the quality of fruits of cornelian cherries while in cold storage might be maintained with the help of edible coating (EC) and MAP treatments. The results of Liao et al. (2023) also showed that fresh-cut pineapples treated with EC + MAP had better performance at preserving storage quality and prolonging shelf life. Islam et al. (2022) reported that jujube fruit quality losses that developed during cold storage and shelf life may be extended by using MAP and *Aloe vera* (AV).

3.5. *Effects of Treatments on the Ascorbic Acid (Vitamin C)*

All treatments had the same ascorbic acid (vitamin C) content on day 5, as the control group (Figure 5). However, on day 10, the EC+EO treatment showed a content of ascorbic acid significantly lower than the control. On day 15 control, EC+EO and MAP+EC+EO treatments all showed a reduction in the amount of ascorbic acid compared to the other treatments. On day 20 EC, control, MAP, and MAP+EC treatments all showed a decrease in ascorbic acid content. On day 25, the EC treatment indicated a substantial drop in ascorbic acid content compared to the other treatments. On day 30, control and EC showed a decrease in ascorbic acid. The result showed that some of the treatments had a favorable impact on the ascorbic acid content of the tomato fruit such as MAP+hot air, MAP+EC+EO and EC+EO treatments, where the ascorbic acid content of these treatments was noted to be slightly higher than the other treatments and control. This indicates that these treatments could be successful in delaying the reduction of ascorbic acid content of tomato fruits. Similar outcomes have previously been reported by Erkan et al. (2005). He pointed out that the use of hot air delayed the elimination of VC and TSS. In further research with 'Satsuma' mandarins, Shen et al. (2013) pointed out that while hot water treatment somewhat raises VC concentration, untreated control fruits show no significant difference. The same results for MAP was noted by Kahramanoğlu and Usanmaz (2019).

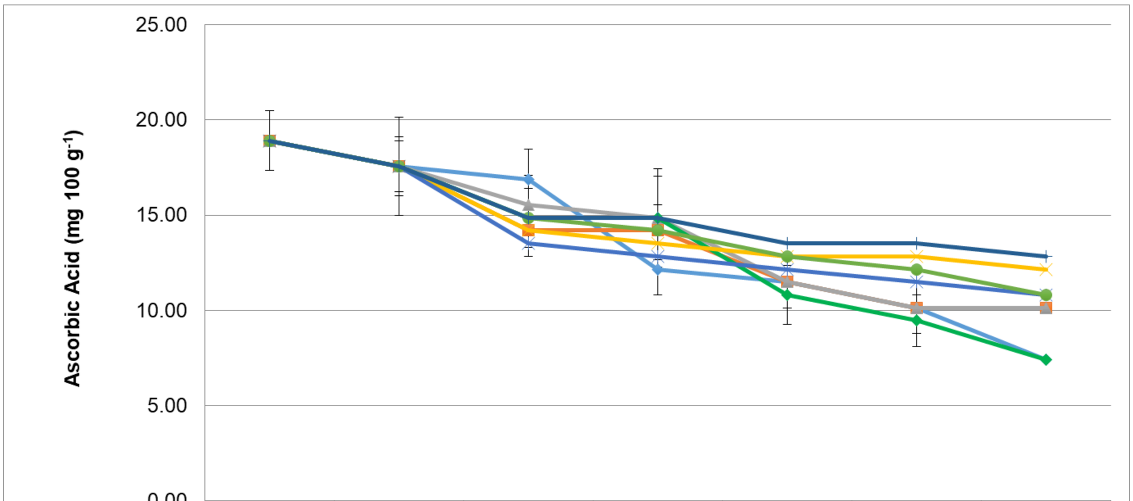
3.6. *Effects of treatments on the chilling injury*

All treatments were effective at minimizing chilling injury in tomatoes compared to the control treatment (see Figure 6). The treatments that consistently indicated the lowest levels of chilling



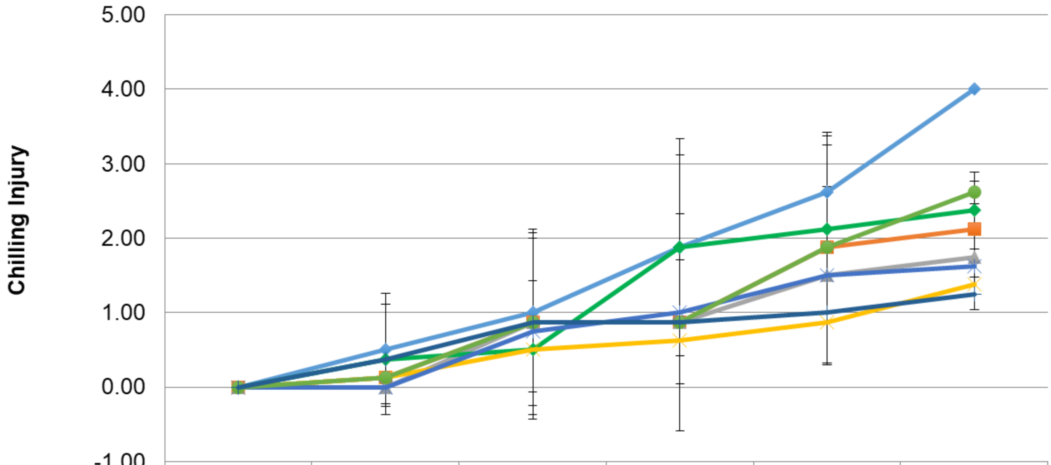
	Day 0	Day 5	Day 10	Day 15	Day 20	Day 25	Day 30
Control	5.38 a	4.68 ab	4.38 a	4.53 a	4.65 a	4.10 a	3.95 a
MAP	5.38 a	4.68 ab	4.75 a	4.68 a	3.93 a	4.48 a	4.48 a
MAP+EC	5.38 a	4.28 b	4.68 a	4.73 a	4.63 a	4.75 a	4.33 a
EC	5.38 a	5.18 ab	5.33 a	4.68 a	4.58 a	3.95 a	3.95 a
MAP+EC+EO	5.38 a	5.03 ab	4.65 a	4.13 a	4.85 a	4.20 a	3.85 a
EC+EO	5.38 a	5.48 ab	4.78 a	4.48 a	4.40 a	3.85 a	4.30 a
Hot Air	5.38 a	5.43 ab	4.80 a	4.83 a	4.48 a	4.25 a	4.28 a
MAP+Hot Air	5.38 a	5.50 a	4.30 a	4.48 a	4.63 a	3.98 a	3.80 a

Figure 4. Soluble solids of the tomato fruits throughout the duration of 30 days of storages influenced by the various treatments. (The means of various treatments are compared independently at each measurement point using the letters in the table below the figure. According to Tukey's HSD, different letters are employed to indicate scientific differences at the $P \leq 0.05$ level.



	Day 0	Day 5	Day 10	Day 15	Day 20	Day 25	Day 30
Control	18.92 a	17.57 a	16.89 a	12.16 a	11.49 a	10.14 ab	7.43 b
MAP	18.92 a	17.57 a	14.19 a	14.19 a	11.49 a	10.14 ab	10.14 ab
MAP+EC	18.92 a	17.57 a	15.54 a	14.86 a	11.49 a	10.14 ab	10.14 ab
EC	18.92 a	17.57 a	14.86 a	14.86 a	10.81 a	9.46 b	7.43 b
MAP+EC+EO	18.92 a	17.57 a	14.19 a	13.51 a	12.84 a	12.84 ab	12.16 a
EC+EO	18.92 a	17.57 a	13.51 a	12.84 a	12.16 a	11.49 ab	10.81 ab
Hot Air	18.92 a	17.57 a	14.86 a	14.19 a	12.84 a	12.16 ab	10.81 ab
MAP+Hot Air	18.92 a	17.57 a	14.86 a	14.86 a	13.51 a	13.51 a	12.84 a

Figure 5. Vitamin C of the tomato fruits throughout the duration of 30 days of storage as influenced by the various treatments. (The means of various treatments are compared independently at each measurement point using the letters in the table below the figure. According to Tukey's HSD, different letters are employed to indicate scientific differences at the $P \leq 0.05$ level.



	Day 5	Day 10	Day 15	Day 20	Day 25	Day 30
Control	0.00 a	0.50 a	1.00 a	1.88 a	2.63 a	4.00 a
MAP	0.00 a	0.13 a	0.88 a	0.88 a	1.88 a	2.13 b
MAP+EC	0.00 a	0.00 a	0.88 a	0.88 a	1.50 a	1.75 b
EC	0.00 a	0.38 a	0.50 a	1.88 a	2.13 a	2.38 b
MAP+EC+EO	0.00 a	0.13 a	0.50 a	0.63 a	0.88 a	1.38 b
EC+EO	0.00 a	0.00 a	0.75 a	1.00 a	1.50 a	1.63 b
Hot Air	0.00 a	0.13 a	0.88 a	0.88 a	1.88 a	2.63 ab
MAP+Hot Air	0.00 a	0.38 a	0.88 a	0.88 a	1.00 a	1.25 b

Figure 6. Chilling injury of the tomato fruits throughout the duration of 30 days of storage as influenced by the various treatments. (The means of various treatments are compared independently at each measurement point using the letters in the table below the figure. According to Tukey's HSD, different letters are employed to indicate scientific differences at the $P \leq 0.05$ level.

injury throughout the 30-day storage period were MAP+hot air, MAP+EC+EO, EC+EO and MAP+EC compared to control. The control showed higher levels of chilling injury compared to all the other treatments. The data suggests that MAP+hot air, MAP+EC+EO, EC+EO and MAP+EC may be effective at reducing chilling injury in tomatoes, and the addition of essential oil (EO) may further enhance this effect. Similarly, Kahramanoğlu and Usanmaz (2019) indicated that MAP enhances fruits' ability to withstand CI. Moradinezhad et al. (2013) suggested that combining hot water with MAP had a greater effect on fruit quality. Similarly, Mastromatteo et al. (2010) study on food preservation, noted that a sealed packaging system with naturally occurring antimicrobials and MAP conditions frequently provides an efficient approach to lengthen the shelf life of food (Moradinezhad et al. 2013).

4. Conclusions

Overall, the findings of this study demonstrated that the combination of MAP technology, edible coatings, essential oils and heat treatment shows promise in comparison to the control group for keeping the postharvest storage quality of tomato fruits. Further research can be conducted to optimize these treatments and explore other eco-friendly methods for enhancing post-harvest preservation and reducing losses in tomato fruits.

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