Original Article
Food Science and Technology

ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)

DOI: https://doi.org/10.1590/fst.110522

Effects of some postharvest essential oil applications on the fruit quality of tomato (*Solanum lycopersicum*) during cold storage

Ahu CEYLAN[1], Halime ÖZDAMAR ÜNLÜ[1*]

Abstract

The effects of post-harvest rosemary and sage essential oils (EO) (0, 300, 600, 900 ppm) on the storage period and fruit quality of 'Sentino F_1' tomatoes were investigated. Tomato fruits were stored at 5 °C and 90-95% relative humidity (RH)) and at +20 °C and 60-65% RH for 30 days. Physical and biochemical analyzes were performed every 5 days during cold storage and at the end of the 2-day shelf life of the samples removed from the cold storage. In conclusion, it was determined that all application groups of sage and rosemary EOs were more effective in maintaining the quality of tomato fruits compared to the control application. The most effective application of sage EO was determined as 600 ppm and 900 ppm doses.

Keywords: tomato; storage; shelf-life; essential oil; quality.

Practical Application: Essential oils may be a good alternative to post-harvest chemical applications.

1 Introduction

The total world production of tomatoes, which is one of the most widely grown herbal products in the world, is 186.821.216 tons. China is the country that produces the most tomatoes in the world (64.865.807 tons), followed by India (20.573.000 tons) and Türkiye (13.204.015 tons) respectively (Food and Agriculture Organization of the United Nations, 2022). Tomato is a vegetable with high contents of phytochemicals (lycopene, β-carotene, polyphenol, and quercetin), Vitamin C, Vitamin E, and high antioxidant capacity (Pinheiro et al., 2013). It has been determined that the 821.296 tons of vegetables produced in our country have been lost during the production period, and 3.072.836 tons have suffered other losses during many different processes after harvest (losses during harvest, transportation, etc.). Among these loss amounts, there are 1.633.465 tons of other losses of tomato (losses during harvest, transportation, etc.) and 462.141 tons of production loss (Türkiye Statistical Institute, 2022).

In the last decade, consumers have shown an increasing interest in natural fruit and vegetable consumption (Pinheiro et al., 2012). In addition, consumers prefer to buy vegetables and fruits that are not processed with pesticides, free from defects and diseases, and suitable for consumption. On the other hand, importing countries apply strict import regulations regarding maximum residue limits in the edible parts of fruits and vegetables (Njombolwana et al., 2013). Chemicals are generally not ideal for reducing the external, internal quality and weight losses that occur after the harvest of the products (Zhang et al., 2022). In this direction, tendencies towards alternative methods to post-harvest chemical applications have increased in the fresh fruit and vegetable sector. Among these alternative methods; controlled and modified atmosphere storage (Falagán & Terry, 2018), biological control agents (Janisiewicz et al., 2001) carbonate, bicarbonate (Palou et al., 2002a) and use of food preservatives such as potassium sorbate (Palou et al., 2002b), ozone application (Palou et al., 2003), heat treatments (Fallik & Ilić, 2018), methyl jasmonate (Tzortzakis, 2007), salicylic acid (Yao & Tian, 2005), UV-C radiation (Simone et al., 2020), microwave oven (Karabulut & Baykal, 2002), chitosan (Bautista-Baños et al., 2006) and essential oils (González-Estrada et al., 2019) can be counted.

The search for natural additives such as essential oils is increasing (Schuh et al., 2022). In particular, essential oils (EOs) produced from miscellaneous aromatic plants such as rosemary, sage, bay leaf, lemongrass, cinnamon, and thyme have been accepted as suitable antimicrobial agents by many researchers because of their antibacterial effects against food-related pathogen bacteria and spoilage. Additionally, the tendency to EOs, the alternative to synthetic additives and generally accepted as safe (GRAS) substances by the Food and Drug Administration is increasing (Gahruie et al., 2017). EOs are a combination of nonvolatile and volatile natural compounds which have antimicrobial and antioxidant properties (Bakkali et al., 2008). Many investigations have been made by many researchers on the chemical contents (Shin et al., 2022), antimicrobial (Chikhoune et al., 2013) and antifungal properties (Almeida et al., 2022) of different Eos. The EOs are approved as antimicrobial agents against several pathogenic and spoilage microorganisms involved in foodborne diseases (Aydogdu et al., 2020).

The postharvest use of chemicals to prevent diseases in vegetables and fruits has become an important problem because of the residue risk and negative effects on human

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Received 04 Oct., 2022
Accepted 02 Dec., 2022

[1] *Department of Horticulture, Faculty of Agriculture, Isparta University of Applied Sciences, Isparta, Türkiye*
*Corresponding author: halimeunlu@isparta.edu.tr

health. The postharvest use of EOs, obtained from various plants and consisting of natural ingredients have becamed an alternative to chemicals because of their antimicrobial and antibacterial effects.

EOs' positive effects on the postharvest quality of horticultural crops have been approved with many research conducted in recent years. They are seen as eco-friendly, intelligent, and sustainable alternatives materials (Moreira et al., 2022). The application of EOs for decay control and postharvest quality in fresh crops is considered a safe practice and hence there is no regulatory problem (Sivakumar & Bautista-Baños, 2014).

In this study, it was aimed to determine the effects of postharvest application of three different doses of rosemary and sage EOs, which can replace the chemicals that have negative effects on the human health and environment, on the quality of tomato fruits in the cold storage and subsequent shelf-life conditions.

2 Materials and methods

In this study, 'Sentino F_1' tomato variety, which was harvested during the red ripening period, was used. The average fruit weight of this variety varies between 20 and 25 grams. The fruit is bright red and round cherry-shaped. Healthy homogeneous tomato fruits without any crushing or puncture damage were selected. Rosemary (*Rosmarinus officinalis*) and sage (*Salvia officinalis*) EOs were used in the study. 0 (control), 300, 600, and 900 ppm doses of these EOs were applied to the fruits as dipping for 30 minutes before storage. After the application, the dipping solution on the tomato fruits was drained, and the fruits were dried and placed into the cold storage with polyethylene crates. The study was set up in a randomized plot design with 3 replications and 10 clusters of fruit in each replication. Storage was carried out at +5 °C and 90-95% relative humidity for 30 days. Analyzes were performed at 5 days intervals during cold storage (at 0th, 5th, 10th, 15th, 20th, 25th and 30th days) and subsequent shelf-life conditions. For the shelf life evaluations, the samples were taken out of the cold storage at the end of every analyzing period (5th, 10th, 15th, 20th, 25th, and 30th days) and were stored at +20 °C and 60-65% relative humidity for 2 days. At the beginning of the storage, 30 fruits were reserved only for the weight loss and color measurement. Tomato fruits were separated into 7 groups, labeled, weighed, and their color was measured. Weight loss and color measurement were performed in the same samples during storage. The weight loss (WL) (Dilmaçünal, 2020), peel color (Dilmaçünal, 2020), firmness (Ağar et al., 1997), titratable acidity (TA) and pH (Cemeroğlu, 2007), soluble solid content (SSC), decay amount, ascorbic acid (Vitamin C) content (Özdemir & Dündar, 1998), total phenolic substance amount (Coseteng & Lee, 1987), lycopene amount (Nagata & Yamashita, 1992), β-carotene amount and sensorial evaluations (calyx rupture and desiccation, external appearance, taste, and flavor) (Dilmaçünal, 2020) were performed during the cold storage and subsequent shelf-life period.

3 Results and discussion

3.1 Weight loss

As a result of the study, it was revealed that all doses of sage and rosemary EOs reduced the weight loss in tomatoes during storage as compared to the control (Table 1). According to the average values the highest value was in the control group in the cold storage (CS) (3.06%) and shelf life (SL) conditions (3.75%) and the lowest weight loss (2.06%) was in the 300 ppm dose of rosemary EO in cold storage and 900 ppm dose of sage EO (2.63%) in the shelf-life conditions. Some researchers also reported reduced weight losses in the investigations on the effects of some EOs in some fruit and vegetable species in line with our findings (Martínez-Romero et al., 2003; Öz & Ulukanlı, 2012).

3.2 Fruit peel color (L, C*, h°)

300 ppm dose of sage EO was better than the other doses in terms of preserving the brightness of the fruit. The rate of decrease in L* value during the shelf life (30 + 2 days) was the highest at 900 ppm dose of rosemary EO (7.71%) but it was the lowest at 300 ppm dose of sage EO (4.90%). It was found that a dose of 300 ppm of sage essential oil was more successful than the others in terms of preserving the fruit brightness throughout the shelf life. Our results show that the brightness of the peel colors of the fruits decreases during storage and the peels of tomato fruits become dull compared to the beginning. Göksel (2011) reported the lowest brightness reduction in carvacrol treated cherry cultivars in a postharvest investigation on the effects of EO components of carvacrol and thujone during storage at 1.5 ± 0.5 °C temperature and 85-90% relative humidity conditions. Öz & Ulukanlı (2012) stated that 600 ppm black cumin oil was effective in maintaining the L* value as a result of 12 days of storage in pomegranate fruits at 4 °C.

The decrease in the C* value during the storage was the highest (11.23%) in the 600 ppm rosemary EO and the lowest (9.59%) in the 900 ppm sage EO. The most decrease in the C* value during the shelf life (30 + 2 days) was obtained from the 600 ppm rosemary EO (4.83%) but the lowest value was observed from the control sample (12.18%). Göksel (2011) stored 3 different cherry varieties under 1.5 ± 0.5 °C temperature and 85-90% relative humidity conditions with thujone and carvacrol by putting in the package and determined that the best application that maintain the C* value was carvacrol. Our results showed that the tomatoes stored in the cold storage are more viable than the tomatoes in shelf-life conditions, but a decrease was determined in C* values with the increase of storage time in both conditions.

The rate of increase in h° value during cold storage was the highest in the control (15.74%), and the lowest (9.54%) in the 900 ppm sage EO. Considering these values, it has been determined that the most effective application in maintaining the h° value is 900 ppm of sage EO. The increase in h° value during the shelf life (30 + 2 days) occurred the most in the control (14.98%) and the least (5.84%) in the 900 ppm application of rosemary EO. Considering these values, it has been determined

Table 1. Effects of some postharvest essential oil applications on the weight loss and color (L*, C*, h°) attributes of tomato fruits throughout cold storage and shelf life.

	Storage Period (Days)															
	Weight Loss (%)															
	0	0 + 2	5	5 + 2	10	10 + 2	15	15 + 2	20	20 + 2	25	25 + 2	30	30 + 2	CSM	SLM
Control	0^{w}	1.01$^{st\ st}$	1.18^{r}	1.78^{no}	1.75^{o}	1.93^{n}	3.06^{j}	3.70^{gh}	3.98^{h}	4.84^{e}	5.07^{e}	5.65^{d}	6.41^{a}	7.38^{a}	3.06 A	3.75 A
Sage 300 ppm	0^{w}	0.68^{tuv}	0.83^{t}	1.74^{no}	1.09^{rs}	1.87^{n}	1.44^{p}	3.21^{ij}	2.86^{k}	3.37^{hi}	4.38^{g}	4.66^{ef}	5.54^{bc}	6.37^{bc}	2.31 B	3.13 B
Sage 600 ppm	0^{w}	0.40^{v}	0.57^{uv}	1.11^{s}	0.96st	1.24^{pq}	1.37^{pq}	2.79^{kl}	2.67^{lm}	3.41^{hi}	4.33^{g}	4.45^{f}	5.02^{e}	6.34^{bc}	2.13 D	2.82 C
Sage 900 ppm	0^{w}	0.39^{v}	0.43^{v}	0.77^{stu}	0.87^{t}	1.06^{s}	1.52^{p}	2.44^{lm}	2.60^{m}	3.01^{jk}	4.34^{g}	4.65^{ef}	5.30^{d}	6.09^{c}	2.15 D	2.63 E
Rosemary 300 ppm ppmppmppm	0^{w}	0.56^{uv}	0.63^{u}	0.64^{uv}	0.82^{t}	1.02st	1.13^{r}	2.66^{klm}	2.80^{kl}	3.18^{ij}	3.66^{i}	3.99^{g}	5.41^{cd}	6.58^{b}	2.06 E	2.66 DE
Rosemary 600 ppm	0^{w}	0.49^{uv}	0.59^{u}	0.76^{stu}	0.85^{t}	1.13^{pqr}	1.24^{r}	2.13^{m}	2.63^{m}	3.26^{ij}	4.24^{g}	4.69^{ef}	5.59^{b}	6.59^{b}	2.16 D	2.75 CD
Rosemary 900 ppm	0^{w}	0.60^{uv}	0.67^{u}	1.48^{op}	1.20^{r}	1.78^{no}	1.41^{p}	2.45^{lm}	2.43^{n}	3.99^{g}	4.56^{f}	4.64^{ef}	5.49^{bc}	6.64^{b}	2.25 C	3.75 A
Mean	0 G	0.59 G	0.70 F	1.18 F	1.08 E	1.43 E	1.60 D	2.80 D	2.85 C	3.58 C	4.37 B	4.68 B	5.54 A	6.57 A		
	Peel Color L* (Lightness)															
Control	39.12$^{a-i\ a-i}$	38.72^{a-f}	39.06^{b-m}	38.02^{a-i}	38.38^{a-m}	37.98^{a-i}	38.12^{b-m}	37.25^{c-l}	37.19^{h-m}	37.00^{f-l}	37.30^{f-m}	36.78^{g-l}	36.09^{m}	35.89^{l}	37.75 B	37.38 B
Sage 300 ppm	39.42^{a-h}	38.95^{a-d}	38.72^{a-k}	38.39^{a-h}	39.52^{a-l}	38.31^{a-h}	37.93^{b-m}	37.80^{a-k}	38.49^{a-l}	37.50^{b-l}	38.19^{a-m}	37.07^{a-l}	37.22^{g-m}	37.04^{e-l}	38.36 AB	37.80 AB
Sage 600 ppm	40.01^{abc}	39.03^{abc}	38.75^{a-k}	38.42^{a-h}	39.08^{a-j}	38.50^{a-h}	39.71^{a-e}	38.76^{a-f}	38.23^{a-m}	38.05^{b-i}	38.93^{a-k}	37.73^{d-l}	36.27^{l-m}	36.19^{i-l}	38.71 A	38.10 A
Sage 900 ppm	39.98^{a-d}	38.98^{abc}	39.59^{a-f}	38.60^{a-g}	39.12^{a-i}	38.49^{a-h}	39.18^{a-h}	38.35^{a-h}	37.98^{b-m}	37.50^{b-l}	38.32^{a-m}	37.40^{b-l}	36.81^{i-m}	36.06^{j-l}	38.71 A	37.91 A
Rosemary 300 ppm	39.78^{a-e}	38.92^{a-e}	39.06^{a-j}	38.41^{a-h}	39.51^{a-g}	38.27^{a-h}	38.21^{a-m}	37.94^{a-j}	37.59^{e-m}	37.51^{b-l}	38.03^{b-m}	37.53^{b-l}	36.68^{k-m}	36.21^{i-l}	38.41 A	37.83 AB
Rosemary 600 ppm	40.23^{ab}	39.59^{a}	40.22^{ab}	39.23^{ab}	39.69^{a-e}	38.74^{a-f}	37.64^{e-m}	37.51^{b-l}	37.66^{d-m}	37.35^{a-l}	37.97^{b-m}	37.75^{b-l}	36.80^{j-m}	36.61^{h-l}	38.60 A	38.11 A
Rosemary 900 ppm	39.66^{a-e}	38.99^{abc}	40.45^{a}	38.95^{a-d}	39.75^{a-e}	38.92^{a-e}	39.35^{a-h}	38.41^{a-h}	37.54^{e-m}	37.04^{e-l}	37.74^{c-m}	37.41^{b-l}	36.13^{m}	35.98^{k-l}	38.66 A	37.96 A
Mean	39.74 A	39.03 A	39.27 A	38.57 AB	39.15 AB AB	38.46 BC	38.59 BC	38.00 C	38.07 CD	37.42 D	37.81 D	37.38 D	36.57 E	36.28 E		
	Peel Color C* (Chroma)															
Control	34.56^{a}	28.22^{a-e}	33.03^{a-e}	27.55^{a-i}	33.40^{a-d}	27.59^{a-h}	33.36^{a-d}	25.91^{c-m}	33.22^{a-d}	24.86^{h-m}	30.05^{g-m}	25.00^{g-m}	30.88^{d-m}	24.78^{l-m}	32.64 A	26.27
Sage 300 ppm	33.95^{abc}	29.18^{a}	34.16^{ab}	27.72^{a-g}	32.33^{a-g}	27.80^{a-f}	31.95^{a-h}	27.36^{a-j}	30.24^{e-m}	25.64^{d-m}	29.70^{g-m}	25.93^{c-m}	30.36^{e-m}	25.24^{f-m}	31.81 BC	26.76
Sage 600 ppm	33.50^{a-d}	28.50^{abc}	33.93^{abc}	26.82^{a-l}	33.78^{abc}	27.36^{a-j}	32.32^{a-g}	26.72^{a-m}	29.79^{g-m}	25.84^{c-m}	29.89^{g-m}	24.45^{klm}	29.89^{g-m}	24.36^{lm}	31.87 AB	26.29
Sage 900 ppm	32.41^{a-g}	27.80^{a-f}	31.79^{a-i}	26.85^{a-l}	31.67^{b-k}	27.74^{a-g}	30.88^{d-m}	25.48^{e-m}	29.80^{g-m}	26.27^{b-m}	28.87^{klm}	25.59^{e-m}	29.30^{h-m}	23.95^{m}	30.68 D	26.24
Rosemary 300 ppm	33.81^{abc}	28.59^{abc}	32.47^{a-g}	27.40^{a-j}	30.05^{g-m}	27.70^{a-g}	31.76^{a-j}	26.44^{a-m}	31.44^{b-l}	25.88^{c-m}	28.29^{m}	25.26^{f-m}	30.17^{f-m}	24.72^{j-m}	31.14 BC	26.57
Rosemary 600 ppm	33.55^{a-g}	28.72^{ab}	32.39^{a-g}	27.71^{a-g}	32.12^{a-h}	29.13^{a}	31.22^{c-l}	27.01^{a-l}	29.44^{h-m}	24.98^{g-m}	28.76^{lm}	25.32^{f-m}	29.78^{g-m}	24.46^{klm}	31.04 CD	26.76
Rosemary 900 ppm	32.38^{a-g}	28.39^{a-d}	31.34^{b-l}	27.88^{a-f}	32.99^{a-f}	28.97^{ab}	30.91^{d-m}	27.17^{a-k}	28.37^{m}	24.76^{j-m}	29.05^{lm}	25.63^{d-m}	28.94^{j-m}	24.53^{klm}	30.57 D	26.76
Mean	33.45 AB	28.49 A	32.73 AB	27.42B	32.34 BC	28.04 AB	31.77 C	26.58 C	30.33 D	25.46 D	29.90 DE	25.31 DE	29.23 E	24.58 E		
	Peel Color h° (hue angle)															
Control	48.27^{c-j}	44.77^{bcd}	48.16^{c-j}	46.08^{a-d}	50.06^{b-h}	48.43^{abc}	52.37^{a-d}	48.01^{abc}	54.19^{ab}	49.55^{abc}	51.98^{a-e}	49.79^{b}	55.87^{a}	51.48^{a}	51.56 A	48.30 A
Sage 300 ppm	46.91^{d-j}	43.40^{cd}	48.01^{c-j}	45.92^{a-d}	46.38^{e-j}	45.99^{a-d}	47.42^{c-j}	45.40^{a-d}	49.71^{b-h}	47.30^{a-d}	50.83^{a-g}	49.40^{abc}	52.74^{abc}	48.17^{abc}	48.86 B	46.51 BC
Sage 600 ppm	45.09^{hij}	43.42^{cd}	46.51^{e-j}	44.57^{bcd}	47.40^{c-j}	41.28^{d}	48.47^{c-j}	45.36^{a-d}	47.12^{c-j}	47.45^{a-d}	48.49^{c-j}	47.88^{abc}	50.84^{a-g}	46.99^{a-d}	48.22 BC	45.28 C
Sage 900 ppm	44.65^{hij}	43.23^{cd}	45.30^{g-j}	43.86^{bcd}	46.19^{f-j}	47.82^{abc}	48.15^{c-j}	45.10^{bcd}	49.15^{b-j}	48.56^{abc}	47.82^{c-j}	40.06^{abc}	48.91^{b-j}	45.80^{a-d}	47.73 BC	46.20 BC
Rosemary 300 ppm	46.60^{e-j}	44.52^{bcd}	46.10^{f-j}	44.11^{bcd}	44.42^{hij}	47.42^{a-d}	47.95^{c-j}	47.62^{a-d}	51.37^{a-f}	48.55^{abc}	48.34^{c-j}	47.88^{abc}	52.77^{abc}	49.84^{ab}	47.70 BC	47.13 AB
Rosemary 600 ppm	45.02^{hij}	43.94^{bcd}	46.05^{f-j}	44.79^{bcd}	47.31^{c-j}	44.14^{bcd}	48.21^{c-j}	47.68^{abc}	46.96^{d-j}	46.51^{a-d}	49.67^{b-i}	49.23^{abc}	50.89^{a-g}	47.90^{abc}	47.17 C	46.31 BC
Rosemary 900 ppm	43.98^{j}	44.85^{bcd}	44.00^{ij}	45.89^{a-d}	49.08^{b-j}	46.78^{a-d}	47.77^{c-j}	45.91^{a-d}	46.14^{f-j}	48.75^{abc}	47.48^{c-j}	47.17^{a-d}	49.47^{b-j}	47.47^{a-d}	46.85 C	46.69ABC
Mean	45.79 D	44.02 D	46.31 D	45.03 CD	47.26 CD	45.98 C	48.62 BC	46.44 BC	49.23 B	48.10AB	43.23 B	48.63 A	51.64 A	48.24 A		

Note: Means (n = 3) followed by the same small letter (within the rows) and capital letter (within the columns) do not differ significantly at $p = 0.05$ (LSD test). CSM: cold storage mean; SLM: shelf life mean.

that the most effective application in maintaining the h° value is 900 ppm of rosemary EO in shelf life conditions. Similar findings with the h° values obtained under the shelf life conditions of this study were also obtained from the studies carried out on the shelf life of tomato fruits at 20 °C for 20 days (Ali et al., 2010) and at 21 °C for 15 days (Chen et al., 2019). Moreover, similar results were also obtained in the strawberries stored at 2 °C for 18 days (Shehata et al., 2020).

3.3 Fruit firmness

It was determined that 300 ppm dose of sage EO (9.84 N) was the most effective application in preserving the fruit firmness at the end of the cold storage period. While the decrease in firmness from the harvest was 26.40% in tomatoes treated with 900 ppm dose of sage EO, a 50.09% decrease was recorded in fruits with 300 ppm dose of rosemary. The most effective application in preserving the fruit firmness under the shelf life conditions was 600 ppm of sage EO (12.30 N). The lowest firmness compared to the initial value was obtained from 600 ppm rosemary EO with a decrease of 57.64%. The fruit firmness of nectarine fruits, in which 1% and 2% doses of *Aloe vera* were applied, was even lower than the control at the end of the shelf-life period (Örnek, 2015). Martínez-Romero et al. (2006) observed similar effects of *Aloe vera* application in cherry fruits. Tzortzakis (2007), didn't find a negative effect from the application of EOs obtained from cinnamon and eucalyptus on the fruit firmness of strawberries and tomatoes. Göksel (2011) determined that thujone and carvacrol applications have a reducing effect on the loss of firmness in cherry fruits in low temperature storage.

3.4 Titratable acidity and pH

While there was a decrease in the amount of TA during 30 days of storage at 5 °C, it was determined that tomatoes treated with sage and rosemary EO were effective in delaying the reduction compared to the control group. The amount of TA, which was 0.516% at the beginning of storage, was found to be the lowest in the control group (0.329%) with a 27.21% reduction at the end of the storage period. While 900 ppm rosemary EO was determined as the most effective application in maintaining the TA (0.360%), a decrease of 22.41% was detected in this application as compared to the initial value (Table 2).

While the 900 ppm dose of rosemary EO was the most effective application in maintaining the TA value under shelf life conditions, a decrease of 15.58% occurred in this application as compared to the initial value. In the control and 600 ppm sage EO applications, a decrease of 21.29% and 23.80% was determined, respectively, compared to the initial value, while the highest reduction (38.54%) was determined in the fruits that were treated with 600 ppm dose of rosemary EO. Martínez-Romero et al. (2006) determined that the *Aloe vera* application preserved the TA content during storage and was accepted as an effective application for fruit quality. In the shelf life evaluation made at the end of the storage period in nectarine fruits where different doses of *Aloe vera* were applied, it was determined that the 4% *Aloe vera* treatment was effective in maintaining the TA value (Örnek, 2015). Göksel (2011) determined that the thujone application had a protective effect on the TA value in the low temperature storage of cherry fruits.

3.5 Soluble solid content

It has been determined that the sage EO applications are effective in delaying the increase in SSC throughout the storage time. The value, which was 3.72% at the beginning of the storage period, varied between 4.83% (control) and 4.16% (300 ppm rosemary EO) at the end of the storage period. It was determined that all doses of the sage essential oil had a positive effect on the SSC content as compared to the rosemary essential oil under shelf-life conditions. Similar to our findings, Göksel (2011) determined that carvacrol application was the most effective application in preserving the amount of SSC in 3 different cherry cultivars stored under 1.5 ± 0.5 °C temperature and 85-90% relative humidity conditions. It was determined that the 4% dose of *Aloe vera* in nectarine fruits, in which different doses were applied, was more effective in preserving the content of SSC under the storage and shelf life conditions compared to other treatments (Örnek, 2015).

3.6 Decay amount

As a result of the study, it was determined that 300 and 600 ppm doses of sage EO applications had a considerably reducing effect on the amount of decay compared to the other applications. It was observed that the 600 ppm dose of sage EO was the best treatment in terms of delaying the decay under the shelf life conditions. Serrano et al. (2004) determined that the use of eugenol, thymol or menthol together with polypropylene bags delayed fruit rot. It was determined that the 4% dose of *Aloe vera* in nectarine fruits, in which different doses were applied, was more effective in reducing the rate of decay compared to the other treatments, both during cold storage and during shelf life conditions (Örnek, 2015).

3.7 Calyx desiccation and rupture

It was observed that the calyx desiccation started from the 20th day of storage and the lowest value was obtained in the 600 ppm application of sage EO (22.22%), but the highest value was obtained in the control samples (54.17%) (Table 3). As a result, it has been determined that the EO applications have a relatively reducing effect on the amount of desiccation in the calyx as compared to the control group. The lowest calyx desiccation value was obtained from the 600 ppm dose of sage EO (32.98%) but the highest value was obtained from the 900 ppm dose of rosemary EO (38.32%) under the shelf life conditions. It was determined that all doses of sage essential oil had a positive effect on the calyx rupture compared to the rosemary essential oil under cold storage and shelf-life conditions.

Table 2. Effects of some postharvest essential oil applications on the fruit firmness, titratable acidity, pH and soluble solids content of tomato fruits throughout cold storage and shelf life.

	Storage Period (Days)															
	Fruit Firmness (N)															
	0	0 + 2	5	5 + 2	10	10 + 2	15	15 + 2	20	20 + 2	25	25 + 2	30	30 + 2	CSM	SLM
Control	14.89^{a-e}	13.19^{a-f}	14.05^{a-g}	12.93^{a-f}	12.58^{d-k}	11.97^{c-i}	12.49^{e-l}	10.23^{i-l}	11.65^{h-m}	10.01^{i-l}	10.97^{i-n}	9.48^{k-n}	9.79^{m-p}	8.47^{mno}	12.34 B	10.90 B
Sage 300 ppm	15.13^{abc}	14.45^{ab}	14.95^{a-d}	13.34^{a-f}	14.53^{a-f}	13.33^{a-f}	13.26^{b-i}	10.62^{g-l}	12.96^{b-j}	10.19^{i-l}	12.17^{f-m}	9.58^{j-m}	9.84^{m-p}	8.70^{l-o}	13.26 A	11.46 B
Sage 600 ppm	15.17^{ab}	14.30^{ab}	14.65^{a-e}	13.95^{abc}	13.46^{a-h}	13.57^{a-d}	13.67^{a-h}	13.29^{a-f}	12.91^{b-j}	12.07^{c-i}	12.52^{e-l}	11.56^{d-k}	9.22^{mno}	7.34^{nop}	13.19 A	12.30 A
Sage 900 ppm	13.37^{a-h}	13.94^{abc}	13.51^{a-h}	12.93^{a-f}	12.89^{b-j}	11.53^{d-k}	12.09^{g-m}	11.64^{d-k}	11.60^{h-m}	11.93^{c-i}	11.96^{g-m}	10.03^{i-k}	9.84^{m-p}	7.46^{m-p}	12.18 B	11.35 B
Rosemary 300 ppm	15.07^{abc}	13.24^{a-f}	13.24^{b-i}	13.05^{a-f}	12.66^{d-k}	12.47^{b-h}	11.96^{g-m}	11.54^{d-k}	11.31^{h-m}	11.21^{f-k}	10.36^{k-o}	9.63j-m	7.52^{p}	7.10^{op}	11.73 B	11.18 B
Rosemary 600 ppm	15.68^{a}	14.85^{a}	13.30^{a-h}	13.26^{a-f}	12.98^{b-j}	11.88^{c-i}	12.91^{b-j}	11.70^{d-j}	11.44^{h-m}	11.39^{e-k}	10.96^{i-n}	10.36^{h}-l	8.58^{nop}	6.29^{p}	12.26 B	11.39 B
Rosemary 900 ppm	14.51^{a-f}	13.44^{a-e}	14.30^{a-g}	12.49^{b-h}	13.55^{a-h}	12.72^{a-g}	12.74^{c-k}	11.28^{e-k}	10.63^{j-n}	10.60^{g-l}	10.17^{l-o}	9.59^{j-m}	8.20^{op}	6.87^{op}	12.02 B	11 B
Mean	14.83 A	13.92 A	14.00 B	13.13 B	13.24 C	12.50 C	12.73 C	11.47 D	11.79 D	11.06 D	11.30 D	10.03 E	9.10 E	7.76 F		
	Titratable Acidity (%)															
Control	0.452^{d-j}	0.418^{b-f}	0.449^{d-j}	0.416^{b-f}	0.455^{d-h}	0.397^{b-f}	0.436^{d-n}	0.387^{c-f}	0.369^{g-o}	0.399^{b-f}	0.347^{j-o}	0.325^{f}	0.329^{o}	0.329^{ef}	0.405 B	0.382 B
Sage 300 ppm	0.455^{d-i}	0.487^{abc}	0.445^{d-m}	0.440^{a-e}	0.460^{c-g}	0.423^{b-f}	0.422^{d-n}	0.395^{b-f}	0.375^{g-o}	0.386^{c-f}	0.394^{e-o}	0.353^{d-f}	0.350^{i-o}	0.362^{d-f}	0.414 B	0.407 AB
Sage 600 ppm	0.613^{a}	0.441^{a-e}	0.511^{a-d}	0.438^{a-f}	0.433^{d-n}	0.434^{a-f}	0.417^{d-o}	0.407^{b-f}	0.416^{d-o}	0.380^{c-f}	0.397^{e-o}	0.371^{d-f}	0.360^{g-o}	0.336^{ef}	0.450 A	0.401 AB
Sage 900 ppm	0.560^{abc}	0.450^{a-d}	0.457^{c-h}	0.419^{b-f}	0.420^{d-o}	0.420^{b-f}	0.413^{d-o}	0.368^{d-f}	0.383^{e-o}	0.377^{c-f}	0.366^{g-o}	0.371^{d-f}	0.343^{k-o}	0.352^{d-f}	0.420 B	0.394 AB
Rosemary 300 ppm	0.585^{ab}	0.504^{ab}	0.483^{b-e}	0.455^{a-d}	0.446^{d-l}	0.417^{b-f}	0.376^{f-o}	0.430^{a-f}	0.341^{m-o}	0.404^{b-f}	0.354^{h-o}	0.349^{d-f}	0.342^{l-o}	0.355^{d-f}	0.418 B	0.416 A
Rosemary 600 ppm	0.485^{b-e}	0.537^{a}	0.441^{d-n}	0.417^{b-f}	0.447^{d-k}	0.410^{b-f}	0.449^{d-j}	0.401^{b-f}	0.370^{g-o}	0.387^{c-f}	0.349^{j-o}	0.343^{d-f}	0.339^{n-o}	0.330^{ef}	0.412 B	0.404 AB
Rosemary 900 ppm	0.464^{c-g}	0.430^{a-f}	0.479^{c-f}	0.429^{a-f}	0.432^{d-n}	0.395^{b-f}	0.414^{d-o}	0.381^{c-f}	0.406^{e-o}	0.372^{d-f}	0.381^{e-o}	0.379^{c-f}	0.360^{g-o}	0.363^{def}	0.420 B	0.393 AB
Mean	0.516 A	0.467 A	0.466 B	0.431 B	0.442 BC	0.414 BC	0.418 C	0.396 C	0.380 D	0.386 CD	0.370 DE	0.356 DE	0.346 E	0.347 E		
	pH															
Control	4.166^{l}	4.393^{e-k}	4.343^{b-l}	4.353^{f-k}	4.216^{kl}	4.413^{e-k}	4.393^{a-k}	4.536^{a-i}	4.460^{a-g}	4.500^{a-k}	4.506^{a-d}	4.663^{a-d}	4.540^{ab}	4.713^{a}	4.375	4.510 A
Sage 300 ppm	4.263^{g-l}	4.276^{k}	4.296^{e-l}	4.340^{g-k}	4.340^{b-l}	4.450^{b-k}	4.346^{b-l}	4.506^{a-k}	4.316^{c-l}	4.546^{a-h}	4.450^{a-g}	4.666^{abc}	4.486^{a-e}	4.683^{ab}	4.355	4.495 AB
Sage 600 ppm	4.260^{g-l}	4.310^{ijk}	4.260^{g-l}	4.356^{f-k}	4.306^{d-l}	4.470^{b-k}	4.380^{a-k}	4.516^{a-j}	4.376^{a-k}	4.506^{a-k}	4.433^{a-j}	4.496^{a-k}	4.473^{a-f}	4.510^{a-k}	4.355	4.452AB
Sage 900 ppm	4.246^{h-l}	4.440^{c-k}	4.276^{f-l}	4.410^{e-k}	4.380^{a-k}	4.486^{a-k}	4.363^{a-l}	4.443^{c-k}	4.346^{b-l}	4.493^{a-k}	4.440^{a-i}	4.520^{a-j}	4.460^{a-g}	4.556^{a-h}	4.359	4.478 AB
Rosemary 300 ppm	4.326^{c-l}	4.276^{k}	4.383^{a-k}	4.333^{g-k}	4.300^{e-l}	4.503^{a-k}	4.433^{a-j}	4.470^{b-k}	4.406^{a-k}	4.466^{b-k}	4.443^{a-h}	4.536^{a-i}	4.550^{a}	4.596^{a-e}	4.406	4.433 B
Rosemary 600 ppm	4.306^{d-l}	4.290^{jk}	4.296^{e-l}	4.430^{d-k}	4.340^{b-l}	4.465^{b-k}	4.390^{a-k}	4.506^{a-k}	4.406^{a-k}	4.566^{a-g}	4.390^{a-k}	4.580^{a-f}	4.516^{abc}	4.656^{a-d}	4.378	4.490 AB
Rosemary 900 ppm	4.236^{j-l}	4.406^{e-k}	4.240^{i-l}	4.364^{e}	4.370^{a-k}	4.449^{d}	4.356^{a-l}	4.496^{a-k}	4.433^{a-j}	4.546^{a-h}	4.476^{a-f}	4.566^{a-g}	4.550^{a}	4.576^{a-f}	4.380	4.498 AB
Mean	4.258 E	4.341 E	4.299 DE	4.364 E	4.321 D	4.449 D	4.380 C	4.496 CD	4.392 C	4.518 BC	4.448 B	4.575 AB	4.510 A	4.613 A		
	Soluble Solid Content (%)															
Control	4.16^{abc}	4.43^{ns}	4.26^{abc}	4.76	4.43^{ab}	4.33	4.33^{abc}	4.36	4.30^{abc}	4.33	4.40^{ab}	4.13	4.83^{a}	4.40	4.39 A	4.39^{ns}
Sage 300 ppm	4.06^{abc}	4.36	4.06^{abc}	4.60	4.16^{abc}	4.53	4.06^{abc}	4.50	4.30^{abc}	4.33	4.26^{abc}	4.20	4.83^{a}	4.43	4.25 AB	4.42
Sage 600 ppm	3.56^{bc}	4.33	3.76^{bc}	4.16	4.03^{abc}	4.00	4.33^{abc}	4.36	4.23^{abc}	4.53	4.26^{abc}	4.43	4.46^{ab}	4.33	4.09 BC	4.30
Sage 900 ppm	3.56^{bc}	4.36	3.90^{abc}	4.13	4.06^{abc}	4.46	4.23^{abc}	4.26	4.00^{abc}	4.36	4.30^{abc}	4.20	4.53^{ab}	4.43	4.09 BC	4.31
Rosemary 300 ppm	3.40^{c}	4.40	3.73^{bc}	4.20	3.93^{abc}	4.23	3.86^{abc}	4.36	3.86^{abc}	4.36	4.06^{abc}	4.26	4.16^{abc}	4.06	4.08 BC	4.27
Rosemary 600 ppm	3.56^{bc}	4.33	3.76^{bc}	4.26	3.96^{abc}	4.23	3.86^{abc}	4.03	4.10^{abc}	4.36	4.06^{abc}	4.03	4.20^{abc}	4.20	3.93 C	4.20
Rosemary 900 ppm	3.73^{bc}	4.36	3.96^{abc}	4.36	3.96^{abc}	4.46	4.13^{abc}	4.33	4.13^{abc}	4.33	4.26^{abc}	4.23	4.43^{ab}	4.30	3.86 C	4.34
Mean	3.72 D	4.36^{ns}	3.92 CD	4.35	4.08 BC	4.32	4.11 BC	4.31	4.13 BC	4.37	4.23 AB	4.21	4.49 A	4.30		

Note: Means (n = 3) followed by the same small letter (within the rows) and capital letter (within the columns) do not differ significantly at $p = 0.05$ (LSD test). CSM: cold storage mean; SLM: shelf life mean.

Table 3. Effects of some postharvest essential oil applications on the sensorial attributes of tomato fruits throughout cold storage and shelf life.

	Storage Period (Days)															
	Decay Amount (%)															
	0	0 + 2	5	5 + 2	10	10 + 2	15	15 + 2	20	20 + 2	25	25 + 2	30	30 + 2	CSM	SLM
Control	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	8.46^{d-g}	12.63^{c-g}	14.16^{c-g}	23.14^{a-e}	30.20^{abc}	5.11 CD	7.54 BCD
Sage 300 ppm	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	3.03^{fg}	6.66^{efg}	8.09^{efg}	17.75^{b-f}	19.52^{b-f}	3.48 D	4.37 CD
Sage 600 ppm	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	4.16^{fg}	7.03^{efg}	12.96^{c-g}	17.77^{b-g}	2.44 D	3.54 D
Sage 900 ppm	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	11.11^{c-g}	12.85^{c-g}	18.70^{b-f}	19.99^{b-f}	27.86^{abc}	30.20^{abc}	8.23 ABC	9.00 ABC
Rosemary 300 ppm	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	10.35^{d-g}	12.22^{c-g}	15.87^{b-g}	18.98^{b-f}	20.58^{a-f}	21.48^{b-e}	6.68 BCD	7.52 BCD
Rosemary 600 ppm	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	13.69^{c-g}	15.92^{c-g}	24.20^{a-d}	26.38^{a-d}	32.70^{ab}	34.14^{ab}	10.08 AB	10.92 AB
Rosemary 900 ppm	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	0^{g}	18.05^{b-f}	20.13^{b-f}	25.59^{a-d}	29.07^{abc}	36.50^{a}	40.80^{a}	11.45 A	12.85 A
Mean	0 D	0 D	0 D	0 D	0 D	0 D	0 D	0 D	7.60 C	10.37 C	15.40 B	17.67 B	24.50 A	27.73 A		
	Calyx Desiccation (%)															
Control	0^{e}	0^{f}	0^{e}	0^{f}	0^{e}	0^{f}	0^{e}	0^{f}	54.17^{b}	62.43^{e}	83.66^{a}	96.29^{ab}	96.29^{a}	100^{a}	31.59 A	36.96 AB
Sage 300 ppm	0^{e}	0^{f}	0^{e}	0^{f}	0^{e}	0^{f}	0^{e}	0^{f}	30.63^{cd}	69.36^{de}	42.59^{bcd}	77.14^{cde}	81.97^{a}	100^{a}	22.17 BC	33.39 AB
Sage 600 ppm	0^{e}	0^{f}	0^{e}	0^{f}	0^{e}	0^{f}	0^{e}	0^{f}	22.22^{de}	71.48^{de}	39.63^{cd}	75.18^{cde}	84.25^{a}	100^{a}	19.44 C	32.98 B
Sage 900 ppm	0^{e}	0^{f}	0^{e}	0^{f}	0^{e}	0^{f}	0^{e}	0^{f}	25.59^{d}	69.73^{de}	41.11^{bcd}	86.06^{a-d}	85.60^{a}	100^{a}	21.75 BC	34.45 AB
Rosemary 300 ppm	0^{e}	0^{f}	0^{e}	0^{f}	0^{e}	0^{f}	0^{e}	0^{f}	31.90^{bcd}	76.94^{cde}	42.06^{bcd}	81.01^{bcd}	85.47^{a}	100^{a}	24.85 BC	35.64 AB
Rosemary 600 ppm	0^{e}	0^{f}	0^{e}	0^{f}	0^{e}	0^{f}	0^{e}	0^{f}	36.31^{bcd}	80.37^{b-e}	50.00^{bc}	91.07^{abc}	89.72^{a}	100^{a}	26.61 AB	37.74 AB
Rosemary 900 ppm	0^{e}	0^{f}	0^{e}	0^{f}	0^{e}	0^{f}	0^{e}	0^{f}	36.11^{bcd}	79.86^{b-e}	52.38^{bcd}	92.13^{abc}	88.88^{a}	100^{a}	26.92 AB	38.32 A
Mean	0 D	0 C	0 D	0 C	0 D	0 C	0 D	0 C	33.84 C	72.88 B	48.77 B	86.08 A	90.73 A	90.55 A		
	Calyx Rupture (%)															
Control	0^{e}	0^{g}	0^{e}	0^{g}	0^{e}	0^{g}	0^{e}	0^{g}	58.33^{bc}	66.13^{e}	87.96^{a}	96.66^{ab}	96.29^{a}	100^{a}	34.65 A	37.54 AB
Sage 300 ppm	0^{e}	0^{g}	0^{e}	0^{g}	0^{e}	0^{g}	0^{e}	0^{g}	38.73^{cde}	51.51f	49.62^{bcd}	80.47^{d}	87.27^{a}	100^{a}	25.09 BC	37.11 AB
Sage 600 ppm	0^{e}	0^{g}	0^{e}	0^{g}	0^{e}	0^{g}	0^{e}	0^{g}	29.62^{e}	64.07^{ef}	40.74^{c-e}	82.22^{d}	84.25^{a}	100^{a}	24.00 BC	35.18 BC
Sage 900 ppm	0^{e}	0^{g}	0^{e}	0^{g}	0^{e}	0^{g}	0^{e}	0^{g}	34.52^{de}	64.60^{e}	48.16^{b-e}	86.06^{bcd}	87.96^{a}	100^{a}	22.08 C	35.81 BC
Rosemary 300 ppm	0^{e}	0^{g}	0^{e}	0^{g}	0^{e}	0^{g}	0^{e}	0^{g}	39.22^{cde}	67.22^{e}	52.38^{bcd}	92.59^{a-d}	91.53^{a}	100^{a}	26.16 BC	33.14 C
Rosemary 600 ppm	0^{e}	0^{g}	0^{e}	0^{g}	0^{e}	0^{g}	0^{e}	0^{g}	45.23^{b-e}	80.37^{d}	54.16^{bcd}	95.83^{abc}	92.80^{a}	100^{a}	27.45 BC	39.45 A
Rosemary 900 ppm	0^{e}	0^{g}	0^{e}	0^{g}	0^{e}	0^{g}	0^{e}	0^{g}	40.27^{cde}	83.56^{cd}	61.30^{b}	96.29^{abc}	96.29^{a}	100^{a}	28.26 B	39.98 A
Mean	0 D	0 D	0 D	0 D	0 D	0 D	0 D	0 D	40.85 C	68.21 C	56.33 B	90.02 B	90.55 A	100 A		
	External Appearance (scale 1-9)															
Control	9.00^{a}	9.00^{a}	9.00^{a}	8.63^{ab}	9.00^{a}	8.33^{abc}	7.00^{b}	6.33^{de}	5.56^{cde}	4.50^{fgh}	3.66^{ghi}	3.00^{i-l}	3.00^{hi}	2.00^{l}	6.61 AB	5.92 C
Sage 300 ppm	9.00^{a}	9.00^{a}	9.00^{a}	8.80^{ab}	9.00^{a}	8.63^{ab}	7.33^{b}	8.66^{ab}	6.66^{bc}	5.00^{fg}	5.00^{ef}	3.00^{i-l}	3.00^{hi}	2.53^{jkl}	6.85 A	6.42 B
Sage 600 ppm	9.00^{a}	9.00^{a}	9.00^{a}	9.00^{a}	9.00^{a}	9.00^{a}	7.00^{b}	9.00^{a}	5.66^{cde}	5.33^{ef}	5.00^{ef}	3.66^{hij}	3.00^{hi}	2.66^{jkl}	6.66 AB	6.80 A
Sage 900 ppm	9.00^{a}	9.00^{a}	9.00^{a}	8.10^{abc}	9.00^{a}	8.73^{ab}	7.33^{b}	8.33^{ab}	5.00^{ef}	5.00^{fg}	5.00^{ef}	3.33^{h-k}	3.00^{hi}	2.86^{i-l}	6.76 A	6.40 B
Rosemary 300 ppm	9.00^{a}	9.00^{a}	9.00^{a}	8.60^{ab}	9.00^{a}	8.43^{ab}	7.00^{b}	7.00^{cd}	5.33^{de}	5.00^{fg}	4.00^{fgh}	3.00^{i-l}	3.33^{hi}	2.00^{l}	6.66 AB	6.14 BC
Rosemary 600 ppm	9.00^{a}	9.00^{a}	9.00^{a}	9.00^{a}	9.00^{a}	7.66^{bc}	6.66^{bc}	7.00^{cd}	5.00^{ef}	5.00^{fg}	5.00^{ef}	3.00^{i-l}	3.00^{hi}	2.00^{l}	6.66 AB	6.09 BC
Rosemary 900 ppm	9.00^{a}	9.00^{a}	9.00^{a}	8.80^{ab}	9.00^{a}	8.20^{abc}	6.33^{bcd}	7.66^{bc}	4.66^{efg}	4.00^{ghi}	4.00^{fgh}	2.20^{k-l}	2.66^{i}	2.66^{jkl}	6.38 B	6.07 BC
Mean	9.00 A	9.00 A	9.00 A	8.70 AB	9.00 A	8.38 B	6.95 B	7.71 C	5.42 C	4.66 D	4.23 D	3.09 E	3.00 E	2.32 F		
	Taste and Aroma (scale 1-5)															
Control	5.00^{a}	5.00^{a}	5.00^{a}	4.70^{ab}	4.60^{abc}	4.50^{ab}	4.53^{abc}	4.36^{abc}	3.60^{de}	3.30^{bcd}	2.66^{fg}	2.66^{fg}	1.66^{h}	1.33^{h}	3.86 B	3.69 BCD
Sage 300 ppm	5.00^{a}	5.00^{a}	5.00^{a}	4.63^{ab}	4.83^{ab}	4.60^{ab}	4.60^{abc}	4.33^{abc}	4.10^{bcd}	4.00^{bcd}	3.00^{ef}	3.00^{ef}	3.00^{ef}	2.66^{fg}	4.23 A	4.03 A
Sage 600 ppm	5.00^{a}	5.00^{a}	5.00^{a}	4.80^{ab}	4.83^{ab}	4.60^{ab}	4.73^{abc}	4.33^{abc}	4.00^{cd}	3.33^{def}	3.00^{ef}	3.00^{ef}	3.00^{ef}	2.00^{gh}	4.22 A	3.86 AB
Sage 900 ppm	5.00^{a}	5.00^{a}	5.00^{a}	4.70^{ab}	4.73^{abc}	4.60^{ab}	4.63^{abc}	4.38^{abc}	3.50^{de}	3.30^{bcd}	3.00^{ef}	3.00^{ef}	2.66^{fg}	2.00^{gh}	4.02 AB	3.75 BC
Rosemary 300 ppm	5.00^{a}	5.00^{a}	5.00^{a}	4.53^{ab}	4.53^{abc}	4.43^{abc}	4.53^{abc}	4.00^{bcd}	3.50^{de}	3.00^{ef}	2.33^{fgh}	2.00^{gh}	2.00^{gh}	2.00^{gh}	3.84 B	3.56 CD
Rosemary 600 ppm	5.00^{a}	5.00^{a}	5.00^{a}	4.50^{ab}	4.33^{abc}	4.30^{abc}	4.53^{abc}	4.00^{bcd}	3.50^{de}	3.00^{ef}	2.33^{fgh}	2.00^{gh}	2.00^{gh}	1.66^{h}	3.82 B	3.49 DE
Rosemary 900 ppm	5.00^{a}	5.00^{a}	5.00^{a}	4.00^{bcd}	4.00^{cd}	3.66^{cde}	4.00^{cd}	3.63^{cde}	3.00^{ef}	2.66^{fg}	2.00^{gh}	2.00^{gh}	1.66^{h}	2.00^{gh}	3.52 C	3.28 E
Mean	5.00 A	5.00 A	5.00 A	4.55 B	4.56 B	4.38 BC	4.50 B	4.15 C	3.61 C	3.22 D	2.57 D	2.47 E	2.28 E	1.90 F		

Note: Means (n = 3) followed by the same small letter (within the rows) and capital letter (within the columns) do not differ significantly at p = 0.05 (LSD test). CSM: cold storage mean; SLM: shelf life mean.

3.8 Sensorial evaluations

External appearance

With the progression of the storage period, a decrease in the external appearance value was determined in all applications, while post-harvest sage essential oil application was found to be effective in delaying this decrease. Control group fruits received the lowest score by the panelists (3.66), followed by the rosemary 300 ppm (4.00) and rosemary 900 ppm (4.00) applications, respectively. It was determined that the tomatoes in this group fell below the marketable limit value of 5 points. At the end of the 25-day period, it was determined that all tomatoes applied with sage essential oil scored above the marketable value. After 15 + 2 days of storage, no application has fallen below the marketable value of 5. While the highest score was given by the panelists to the tomatoes treated with 600 ppm (5.33) of sage EO on 20 + 2 days of storage, followed by 300 and 900 ppm (5.00) of sage EO and 300 and 600 ppm of rosemary EO, respectively, the lowest score (4.00) was given to 900 ppm dose of rosemary EO. In a study, it was revealed that the application of *Aloe vera* in grapefruits has benefits in extending the storage period without changing the unique appearance of the fruit during storage (Martínez-Romero et al., 2006). In another study, it was reported that the Müşküle grape variety received higher scores when menthol was applied under cold storage conditions than the control application (Göksel, 2011).

Taste and aroma

After the 20th day of storage, it was determined that the fruits lost their flavor and aroma in all applications except 300 and 600 ppm doses of sage EO. After 20 + 2 days of shelf life conditions, it was observed that the fruits in all applications have lost their taste and aroma to a large extent, except for the fruits treated with 300 ppm dose of sage EO. In a study, it was revealed that *Aloe vera* application has benefits in extending the storage period without changing the unique taste and aroma of grapefruits during storage (Martínez-Romero et al., 2006). Moreover, Göksel (2011) determined that the application that best preserves the taste and aroma values at the end of the storage in the Sweetheart, 0900 Ziraat, and Regina cherry varieties was the thujone application.

3.9 Ascorbic acid (vitamin C) content

The highest decrease rate in the amount of ascorbic acid during storage was obtained from the control (47.91%), but the lowest from the 900 ppm dose of rosemary EO (34.61%) and 600 ppm dose of sage EO (39.88%) treatments. The highest rate of decrease in the amount of ascorbic acid during the shelf life (30 + 2 days) was obtained from the 600 ppm dose of rosemary EO (46.77%) and the control (46.41%), but the lowest from the 900 ppm dose of rosemary EO (33.57%). Barreto et al. (2016) found that oregano (*Origanum vulgare*) essential oil and chitosan-treated cherry tomatoes preserved the amount of ascorbic acid better than the control group tomatoes. Moreover, Öz & Ulukanlı (2012), in their study on pomegranate fruits, determined that 300 and 600 ppm black seed oil + starch coating application protected the vitamin C content better than the control group fruits. Similar to the previous findings, it was determined that the loss of ascorbic acid in the EO applied tomatoes was less than the control group in this study.

3.10 Total phenolic substance amount

When the average values were examined, the highest total phenolic content was obtained in 600 ppm dose of sage EO (0.70 mg/g), while the lowest value was determined in the fruits treated with 900 ppm dose of rosemary EO (0.65 mg/g). The highest rate of increase in the total amount of phenolic substances during the storage period was obtained from the control (95.23%), and the 300 ppm dose of sage EO (82.97%) treatment, but the lowest from the 300 ppm dose of rosemary EO (70.90%) treatment. The highest rate of increase in the total amount of phenolic substances during the shelf life was obtained from the control (107.23%) and the 300 ppm dose of sage EO (101.92%) treatment, but the lowest from the 900 ppm dose of sage EO (83.67%) application. Göksel (2011) determined that thujone and carvacrol applications were effective on the phenol metabolism and that all of the applications increased the total amount of phenolic substances more than the control group. The results of our study are similar to these results, and it was found that the amount of phenol increased in all groups, but the increases were higher in the essential oil applied groups.

3.11 Lycopene amount

The highest rate of decrease in the amount of lycopene during storage was obtained from the control (75.58%) and the lowest from the 900 ppm dose of sage EO (64.97%). The highest rate of decrease in the amount of lycopene during the shelf life was obtained from the control (75.71%), but the lowest from 600 ppm dose of rosemary EO (67.47%), and 900 ppm dose of sage EO (67.98%). Consistent with our study, Ajlouni et al. (2001) reported that the lycopene value in the tomato fruits, which was 60 μg/g at the beginning of the storage, decreased to 30 μg/g at the end of the 21 days of the storage.

3.12 β-carotene amount

When the shelf life was evaluated alone in the study, the highest β-carotene value was obtained from the 30th day of the storage (1.17 mg/100 g) compared to the average values. β-carotene contents increased with the increase in storage period (Table 4). The highest rate of increase in β-carotene values during the cold storage was obtained from the 600 and 900 ppm doses of sage EO (122.22%), but the lowest content was observed from the control (107.84%). The highest rate of increase in β-carotene values during the shelf life was obtained from 900 ppm (53.48%) of sage EO and the lowest from the control (44.59%).

Table 4. Effects of some postharvest essential oil applications on the sensorial attributes of tomato fruits throughout cold storage and shelf life.

	Storage Period (Days)															
	Ascorbic Acid (Vitamin C) Content (mg/100 mg)															
	0	0 + 2	5	5 + 2	10	10 + 2	15	15 + 2	20	20 + 2	25	25 + 2	30	30 + 2	CSM	SLM
Control	13.67^{ab}	13.51^{bc}	12.09^{b-i}	12.48^{d-g}	10.48^{i-n}	10.59^{i-m}	10.51^{i-n}	10.70^{ijk}	8.57^{o-r}	8.65^{qr}	8.10^{p-r}	7.97^{s-v}	7.12^{s}	7.24^{v}	10.08 B	10.16 D
Sage 300 ppm	14.37^{a}	14.10^{ab}	13.18^{a-d}	13.24^{b-e}	11.70^{d-i}	11.28^{hij}	11.41^{e-j}	11.37^{hij}	8.82^{o-r}	8.35^{stu}	7.78^{r}	8.34^{stu}	8.07^{p-r}	8.14^{stu}	10.76 A	10.69 C
Sage 600 ppm	13.34^{abc}	13.73^{ab}	12.81^{a-e}	12.43^{e-g}	11.17^{f-l}	11.45^{hi}	10.71^{h-m}	10.25^{k-n}	10.84^{g-m}	10.64^{i-l}	9.53^{m-q}	9.78^{lmn}	8.02^{qr}	8.44^{stu}	10.92 A	10.96 AB
Sage 900 ppm	13.12^{a-d}	13.55^{bc}	12.47^{b-f}	12.51^{def}	10.55^{h-m}	10.29^{k-n}	10.86^{f-m}	10.33^{k-n}	9.49^{m-q}	9.72^{mno}	8.36^{p-r}	8.66^{s}	7.19^{s}	7.65^{uv}	10.29 B	10.39 D
Rosemary 300 ppm	14.12^{a}	14.52^{a}	12.96^{a-e}	12.46^{d-g}	11.99^{c-i}	11.76^{fgh}	10.97^{f-m}	10.55^{j-m}	9.55^{l-q}	9.73^{mno}	8.67^{o-r}	8.60st	7.61^{r}	7.88^{s-v}	10.84 A	10.78 BC
Rosemary 600 ppm	14.27^{a}	14.56^{a}	13.25^{a-d}	13.32^{bcd}	12.16^{b-h}	12.70^{cde}	11.18^{f-k}	11.26^{hij}	9.66^{k-p}	9.30^{opq}	8.92^{n-r}	8.74^{s}	7.55^{r}	7.75^{tuv}	11 A	11.09 A
Rosemary 900 ppm	13.26^{a-d}	13.58^{bc}	12.34^{b-g}	12.44^{d-g}	11.01^{f-m}	11.47^{hi}	11.70^{d-i}	11.61^{gh}	10.02^{j-o}	10.68^{ijk}	9.98^{j-o}	9.63^{nop}	8.67^{o-r}	9.02^{o-r}	11 A	11.20 A
Mean	13.73 A	13.93 A	12.73 B	12.70 B	11.29 C	11.36 C	11.05 C	10.87 D	9.56 D	9.58 E	8.76 E	8.82 F	7.75 F	8.02 G		
	Total Phenolic Substance Amount (mg/g)															
Control	0.42^{ns}	0.55	0.54	0.63	0.63	0.79	0.77	0.76	0.73	0.84	0.80	1.00	0.82	1.14	0.67^{ns}	0.81 A
Sage 300 ppm	0.47	0.52	0.57	0.52	0.69	0.60	0.61	0.75	0.76	0.82	0.84	0.93	0.86	1.05	0.69	0.74 B
Sage 600 ppm	0.51	0.52	0.59	0.49	0.69	0.62	0.72	0.74	0.69	0.83	0.81	0.95	0.88	1.01	0.70	0.74 B
Sage 900 ppm	0.48	0.49	0.58	0.47	0.67	0.64	0.60	0.74	0.76	0.81	0.81	0.94	0.85	0.90	0.68	0.71 B
Rosemary 300 ppm	0.55	0.51	0.46	0.61	0.57	0.59	0.66	0.75	0.75	0.82	0.88	0.94	0.94	1.00	0.69	0.75 AB
Rosemary 600 ppm	0.50	0.52	0.58	0.61	0.57	0.74	0.64	0.70	0.76	0.80	0.81	0.91	0.88	1.02	0.68	0.76 AB
Rosemary 900 ppm	0.51	0.51	0.41	0.58	0.52	0.62	0.61	0.72	0.79	0.87	0.83	0.84	0.88	0.96	0.65	0.73 B
Mean	0.49 F	0.52 F	0.53 EF	0.56 F	0.62 DE	0.66 E	0.66 CD	0.74 D	0.75 BC	0.82 C	0.82 AB	0.93 B	0.87 A	1.01 A		
	Lycopene Amount (mg/100 g)															
Control	9.01^{ab}	10.91^{a}	6.37^{d-g}	7.44^{bcd}	5.50^{g-j}	5.56^{efg}	4.08^{k-r}	3.47^{hij}	3.30^{m-r}	3.10^{ij}	3^{q-r}	3.00^{ij}	2.20^{s}	2.65^{j}	4.78 B	5.16 C
Sage 300 ppm	9.62^{a}	11.81^{a}	7.50^{cde}	8.69^{b}	6.35^{efg}	6.37^{def}	4.49^{i-m}	5.56^{efg}	3.57^{k-r}	4.37^{ghi}	3.27^{m-r}	4.05^{g-j}	2.92^{r}	3.71^{hij}	5.39 A	6.37 AB
Sage 600 ppm	9.59^{a}	11.42^{a}	7.86^{bc}	8.47^{bc}	6.26^{fg}	6.80^{def}	4.65^{h-k}	4.16^{g-j}	4.20^{k-q}	4.05^{g-j}	3.66^{k-r}	3.56^{hij}	2.90r	3.34^{hij}	5.59 A	5.97 B
Sage 900 ppm	9.28^{a}	11.15^{a}	7.45^{c-f}	8.58^{b}	5.68^{ghi}	6.29^{def}	4.28^{j-p}	5.49^{fg}	3.54^{k-r}	4.22^{gh}	3.64^{k-r}	3.58^{hij}	3.25^{n-r}	3.57^{hij}	5.30 A	6.12 B
Rosemary 300 ppm	9.58^{a}	11.03^{a}	7.61^{cd}	8.93^{b}	5.86^{gh}	6.41^{def}	4.56^{i-l}	4.62^{gh}	3.41^{k-r}	4.31^{ghi}	3.22^{o-r}	3.45^{hij}	3.10^{pqr}	3.21^{hij}	5.33 A	5.99 B
Rosemary 600 ppm	9.69^{a}	11.19^{a}	7.47^{c-f}	10.53^{a}	5.63^{ghi}	7.05^{cde}	4.44^{i-o}	6.23^{gh}	3.93^{k-r}	4.42^{gh}	3.43^{k-r}	3.69^{hij}	3.18^{pqr}	3.64^{hij}	5.39 A	6.68 A
Rosemary 900 ppm	9.37^{a}	11.46^{a}	7.39^{c-f}	8.60^{b}	5.60^{ghi}	6.29^{def}	4.47^{i-n}	4.63^{gh}	3.35^{l-r}	4.10^{g-j}	3.72^{k-r}	4.15^{g-j}	3.18^{pqr}	3.66^{hij}	5.30 A	6.13 B
Mean	9.45 A	11.28 A	7.38 B	8.75 B	5.84 C	6.40 C	4.43 D	4.88 D	3.61 E	4.08 E	3.42 E	3.64 F	2.96 F	3.40 F		
	B-Carotene Amount (mg/100 g)															
Control	0.51^{o}	0.74^{m}	0.57^{mno}	0.77^{lm}	0.66^{l-o}	0.88^{i-m}	0.74^{i-o}	0.86^{j-m}	0.84^{d-o}	0.89^{h-m}	0.94^{a-l}	0.93^{f-m}	1.06^{a-k}	1.07^{a-m}	0.76 B	0.88 D
Sage 300 ppm	0.55^{mno}	0.90^{g-m}	0.76^{g-o}	0.97^{e-m}	0.86^{b-o}	1.02^{c-m}	0.85^{b-o}	1.08^{a-l}	1.06^{a-j}	1.10^{a-k}	1.11^{a-g}	1.18^{a-j}	1.15^{a-e}	1.36^{ab}	0.91 A	1.09 ABC
Sage 600 ppm	0.54^{mno}	0.85^{j-m}	0.76^{g-o}	0.90^{g-m}	0.84^{d-o}	1.01^{c-m}	0.85^{c-o}	1.06^{a-m}	1.08^{a-i}	1.13^{a-k}	1.18^{a-d}	1.17^{a-k}	1.20^{ab}	1.29^{a-e}	0.92 A	1.06 ABC
Sage 900 ppm	0.54^{mno}	0.86^{j-m}	0.68^{l-o}	0.85^{j-m}	0.78^{f-o}	0.90^{g-m}	0.85^{b-o}	0.99^{c-m}	1.07^{a-i}	1.04^{b-m}	1.08^{a-i}	1.04^{b-m}	1.20^{abc}	1.32^{abc}	0.89 A	1.00 C
Rosemary 300 ppm	0.57^{mno}	0.84^{klm}	0.71^{j-o}	0.98^{d-m}	0.70^{l-o}	1.06^{a-m}	0.87^{b-n}	1.14^{a-k}	1.09^{a-i}	1.26^{a-f}	1.09^{a-h}	1.21^{a-i}	1.26^{a}	1.28^{a-e}	0.90 A	1.11 AB
Rosemary 600 ppm	0.56^{mno}	0.91^{g-m}	0.82^{e-o}	0.97^{d-m}	0.86^{b-o}	1.06^{a-m}	0.89^{b-m}	1.22^{a-g}	1.12^{a-f}	1.22^{a-h}	1.10^{a-h}	1.29^{a-e}	1.19^{abc}	1.38^{a}	0.93 A	1.15 A
Rosemary 900 ppm	0.53^{no}	0.86^{j-m}	0.71^{k-o}	0.89^{i-m}	0.77^{f-o}	0.97^{d-m}	0.83^{d-o}	0.99^{c-m}	0.81^{e-o}	1.05^{a-m}	1.07^{a-i}	1.13^{a-k}	1.15^{a-e}	1.30^{a-d}	0.84 AB	1.03 BC
Mean	0.54 E	0.85 E	0.72 D	0.90 DE	0.78 CD	0.98 CD	0.84 C	1.05 BC	1.01 B	1.10 B	1.08 AB	1.14 B	1.17 A	1.28 A		

Note: Means (n = 3) followed by the same small letter (within the rows) and capital letter (within the columns) do not differ significantly at p = 0.05 (LSD test). CSM: cold storage mean; SLM: shelf life mean.

4 Conclusion

As a result, it was observed that the essential oil applications to the 'Sentino F_1' tomato cultivar were effective in preserving the storage time and fruit quality characteristics under cold storage and shelf-life conditions. When all parameters were evaluated, it was concluded that the tomato fruits could be stored for 25 days at +5 °C temperature, 90-95% relative humidity, and 20 + 2 days at +20 °C temperature with 60-65% relative humidity. When the effectiveness of essential oils was compared, it was found that the best results were obtained from the applications of 900 and 600 ppm doses of sage essential oil.

The chemicals used in the crops after harvesting is an important problem due to the residue leaving and is one of the important factors affecting human health negatively. The use of essential oils obtained from plants in post-harvest storage is thought to be an alternative method for chemicals that have negative effects on human health and the environment while avoiding product losses that may occur during storage in tomato fruits. According to the findings, it has been determined that the use of sage essential oil in tomatoes after harvest is commercially recommended due to its positive contribution to fruit quality characteristics as well as being safe for human health and the environment.

Acknowledgements

This work is derived from master's thesis and was supported by Süleyman Demirel University Scientific Research Projects Coordination Unit (5064-YL1-17).

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