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# Derim Öncesi Salisilik Asit Uygulamasının Soğukta Depolama Boyunca Taze Kekiğin (*Origanum onites* L.) Kalite Özellikleri Üzerine Etkisi

Serhat AKYÜZ[1*], Mehmet Ali KOYUNCU[2]

**Öne Çıkanlar:**
- Derim öncesi SA uygulamaları kekiğin solunum hızını azaltmıştır
- SA uygulanan kekiklerin karvakrol içeği kontrole göre nispeten daha yüksek bulunmuştur
- SA uygulamaları kekiğin kalitesini korumuştur

**Anahtar Kelimeler:**
- Origanum onites L.
- Muhafaza
- Uçucu yağ
- Salisilik asit

**ÖZET:**

Derim öncesi salisilik asit (SA) uygulamasının soğukta depolama boyunca taze kekiğin (*Origanum onites* L.) bazı kalite ve yağ özellikleri üzerine etkisi incelenmiştir. SA uygulamaları için kekikler arazi üzerinde 3 gruba ayrılmıştır. Birinci grup kekiklere tam çiçeklenmeden 20 gün önce 1.5 mM SA uygulaması yapılmıştır. İkinci grup ve kontrol örneklerine tam çiçeklenmeden 10 gün önce sırasıyla 1.5 mM SA ve sadece saf su uygulaması yapılmıştır. Tam çiçeklenme döneminde derilen kekikler hemen laboratuvara nakledilmiştir. MAP'lara yerleştirilen kekikler, 1°C ve %90 ± 3 oransal nemde 25 gün depolanmıştır. Soğukta depolama boyunca ağırlık kaybı, yaprak rengi, solunum hızı, etilen üretimi, MAP içi gaz bileşimi, uçucu yağ ve karvakrol içeriği analizleri ile duyusal değerlendirmeler yapılmıştır. SA uygulanmış kekikler kontrol örneklerine kıyasla solunum hızı, etilen üretimi, karvakrol içeriği ve dış görünüş bakımından daha iyi sonuçlar vermiştir. Sonuç olarak, derim öncesi SA uygulamasının MAP içerisinde depolanan taze kekiklerde, kalite kayıplarının geciktirilmesi bakımından ümitvar olabileceği belirlenmiştir.

# The Effect of Preharvest Salicylic Acid Treatment on Quality Characteristics of Fresh Thyme (*Origanum onites* L.) During Cold Storage

**Highlights:**
- Respiration rate of thyme was decreased by preharvest SA treatments
- The carvacrol contents of SA-treated thymes were relatively higher than control
- SA treatments maintained the marketable quality of thymes

**Keywords:**
- Origanum onites L.
- Preservation
- Essential oil
- Salicylic acid

**ABSTRACT:**

The effect of preharvest salicylic acid (SA) treatments on some oil quality and characteristics of fresh thyme (*Origanum onites* L.) during storage were investigated. The thyme plants were grouped in three blocks for each SA treatment in an orchard. The first group of plants was treated with 1.5 mM SA 20 days before the bloom stage. The second and third group thymes were treated with 1.5 mM SA and only tap water (control), respectively, 10 days before full bloom. The thyme plants harvested at the full bloom stage were transported immediately to the laboratory. The thyme samples were placed in modified atmosphere packaging (MAP) bags and were stored at 1°C and 90 ± 3% relative humidity (RH) for 25 days. Weight loss, leaf color, respiration rate, gas composition in MAP, ethylene production, essential oil and carvacrol content, and sensory quality of thymes were determined during cold storage. SA-treated thymes gave better visual quality, respiration rate, carvacrol content, and ethylene production than the control. As a result, it was determined that preharvest SA treatment could be a promising tool for delaying quality losses in thyme during storage in MAP.

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## INTRODUCTION

Thyme is a plant with a history of thousands of years, symbolizing courage, wealth, and nobility during ancient times. The demand for natural products has increased with the discovery of alternative use areas of aromatic and medicinal plants from the end of the nineteenth century. This has caused interest in aromatic plants worldwide and increased the volume of their daily use (Bayram et al., 2010). Due to the diversity in their chemical and aromatic properties, Origanum species are used to flavor food products and in the perfume industry. They also have many pharmacological properties, including antiseptic, antibiotic, antioxidant, and antimicrobial activities. Güler & Liman (2005) reported that higher vitamin B12 was determined in thyme compared to garlic, lettuce, spinach, parsley, mint and leek plants.

Different organs of the thyme plants are used according to consumption purposes. All above-ground organs are used when the thymes are evaluated as fresh, but their leaves of them are consumed as a spice, in general. The above-ground organs (flower, leaf, and stem) of thyme are also used in the drug industry to obtain essential oil. The essential oils obtained from *Thymbra*, *Origanum*, and *Satureja* contain high levels of carvacrol. Carvacrol, with its antibacterial and antifungal (especially against aflatoxin-producing *Aspergillus fungi*) effects, extends the postharvest life of products by decreasing the microbial load (Koparal & Zeytinoğlu, 2003).

Pre- and postharvest treatments in medicinal and aromatic plants are essential in the production chain as they directly affect product quality. Fresh products after harvest contain a high percentage of water. In order to minimize the quality losses of fresh products, they should be transported to suitable conditions as soon as possible after harvest. When the postharvest storage conditions are not created well, there are severe losses in the essential oil yield of aromatic and medicinal plants, and significant changes are observed in the essential oil composition. The optimal harvest time, method, and suitable storage conditions for fresh products are essential in reducing quality losses. In addition, many methods, such as MAP, edible coating, low-temperature storage, dipping treatments, etc., have been proposed to extend the postharvest life and quality of fresh-cut products (Albanese et al., 2007). Protective methods containing MAP and vacuum packaging were developed to reduce postharvest quality losses of intact and fresh-cut products. Recently, many fresh-cut horticultural crops have been stored in MAP in combination with cold storage or other techniques.

SA is a leading phenolic compound obtained from plants, and it regulates respiration rate, cell growth, senescence, seedling development, seed germination, temperature tolerance, and many other physiological processes (Vlot et al., 2009; Vicente & Plasencia, 2011). SA, which has a significant role in the plant's response against pathogens, also acts as a regulator in the flowering of thermogenic and odor-producing plants (Vlot et al., 2009). In addition, it was reported to be effective on nutrient content, leaf area and number, plant weight and height, photosynthetic pigment content, and microelement content in plants. Studies have shown that SA increases the essential oil content and changes some oil characteristics in basil and marjoram (Gharib, 2006). The treatments such as foliar SA, citric acid, and chitosan increase the essential oil content of thymes (Miri et al., 2015; Emami Bistgani et al., 2017). It was reported that very high doses of SA had a reducing effect on essential oil content, while the appropriate dose significantly increases the content of essential oil in plants (Saharkhiz & Goudarzi, 2014; Momeni et al., 2020).

The present study aimed to extend the cold storage life and reduce the quality losses of thyme by preharvest SA treatment. In addition, changes in essential oil and carvacrol content, the main active ingredient in the oil, were investigated.

## MATERIALS AND METHODS

### Research material and salicylic acid treatments

*Origanum onites* L. thyme was used as plant material in the present study. The study was carried out in two stages, preharvest and postharvest. Preharvest studies were carried out on a 2-year-old thyme plot at the Egirdir Fruit Research Institute. 1.5 mM SA (Merck ≥ 99.0%) + 0.01% Tween-20 solution was applied to the thyme plants 10 ($SA_{10}$) and 20 days ($SA_{20}$) before the full flowering period (80-90% of the plants were in bloom). Only distilled water + 0.01% Tween-20 solution was applied at the same stage to the control groups.

### Harvest, packaging, and storage

At the stage when 80-90% of the thyme had white flowers with pseudo-umbrella structure, the plants were harvested from a height of 6-8 cm from the soil surface in the early hours of the morning. Harvested thyme plants were transported immediately to the Laboratory. The thymes which have yellow leaves and damaged parts were removed from the research material. After homogenization, the plant material was precooled with forced air. Fresh thyme samples (1000 ± 100 g) packaged in MAP bags (low-density polyethylene) were stored in a normal (air) atmosphere (21% $O_2$ and 0.03% $CO_2$) for 25 days at 1°C and 90 ± 3% RH. The following analyzes were carried out on thyme samples during cold storage at the beginning (at harvest) and at 5-day intervals.

### Physical and chemical analysis

The weight loss of thyme was calculated in percent (%) by weighing samples with a digital balance (Scaltec SBA51) according to the initial weight. Changes in leaf color were determined with a Minolta (CR-300- Tokyo, Japan) color meter calibrated with a standard calibration plate. The L*, a*, and b* values of thyme leaf were measured, and the C* and h° values were calculated according to the given formula (1) (Koyuncu et al., 2018).

$$h° = tan^{-1}(b^*/a^*) \quad C^* = [(a^*)2+(b^*)2]^{1/2} \tag{1}$$

The ethylene level and respiration rate of fresh thymes were measured using gas chromatography (GC). The 55±5 g thyme sample weighted in 0.5 L gas-tight containers was kept for 2 hours at 20 ± 1°C. Then, the gas samples taken from the containers were injected into the gas chromatography (Agilent GC-6890N) by using a gas-tight syringe. The carrier gas flow (in constant flow mode) was 1.7 ml/min. The oven, TCD, and FID temperatures were set to 40°C, 250°C and 250°C, respectively. The flows of gas for H2 and dry air were 30 and 300 ml/min, respectively. High purity helium (He) and reference gas flow rates were 7.0 and 20 ml/min, respectively. (Dilmaçünal et al., 2014).

Gas compositions ($CO_2$ and $O_2$) in modified atmosphere bags were measured as percent (%) with an infrared gas analyzer (Systec Instrument Gaspace) during storage.

Essential oils were obtained from 200 g fresh thyme samples by the Clevenger hydrodistillation (water vapor) method. 1000 ml of water was added to the samples and heated with a balloon heater at a temperature between 100-120°C for 3 hours. The essential oil content accumulated in the graduated cylinder was determined as percent (%). For the GC-MS analysis, the oil samples were kept at +4°C. The analysis of essential oil components was carried out by GC and GC-MS (Agilent Model: 7890B) using the HP-Innowax column. As carrier gas helium (99.999%) was used, the flow rate was 1.3 ml/min. The injector and MS transfer temperatures were set at 250°C and 270°C, respectively. The temperature of the column was increased to 70°C for the first 5 minutes and then to 160°C, and after being held at

this temperature for 5 minutes, it was increased to 250°C. In the splitless (40:1) method, 1.0 µl of diluted samples were injected with a delay time of 8.2 minutes (Baydir et al., 2021).

The external appearance of thyme samples was determined using a hedonic scale (poor quality or unmarketable quality:1–4; thymes at marketable quality: ≥ 5; thymes at good quality: 7–8; thymes at excellent quality: 9) according to Erbaş and Koyuncu (2016).

### Statistical analysis

A completely randomized plot design with 3 replications was used. The obtained data were subjected to analysis of variance using the JMP7 package program, and the differences between the averages (storage period and treatments) were grouped according to Tukey's test.

## RESULTS AND DISCUSSION

### Weight loss

The effect of storage time and SA applications on the weight loss of thyme was statistically significant (Table 1). The weight loss of thyme increased parallel to the storage time ($P<0.05$). The average weight loss, which was 0.08% on the 5th day, reached 0.78% on the 25th day of cold storage. In thymes samples, the highest weight loss was determined from the $SA_{10}$ treatment with 0.82%, followed by the control (0.78%) at the end of cold storage. The least weight loss (0.74%) was determined from the $SA_{20}$ treatment.

**Table 1.** The effect of preharvest SA treatment on weight loss of thyme during cold storage (%)

| | Storage period (day) | | | | | |
|---|---|---|---|---|---|---|
| T | 5 | 10 | 15 | 20 | 25 | Avg. |
| C | 0.05j | 0.25h | 0.42f | 0.57d | 0.78ab | 0.42B |
| $SA_{20}$ | 0.12ı | 0.25h | 0.44ef | 0.55d | 0.74b | 0.42B |
| $SA_{10}$ | 0.08ıj | 0.30g | 0.47e | 0.62c | 0.82a | 0.46A |
| Avg. | 0.08E | 0.27D | 0.44C | 0.58B | 0.78A | |
| | | *SP* | | *T* | *SP × T* | |
| | | ** | | ** | * | |

The differences between the means in the same row and column indicated with different letters were statistically significant. ($P<0.05$). Avg.: Average, T: Treatments, C: Control, SP: Storage period, SP×T: Interaction between storage period and treatments, $SA_{10}$: SA treatment 10 days before harvest, $SA_{20}$: SA treatment 20 days before harvest, *: $P<0.05$, **: $P<0.01$

### Leaf color

The changes in the leaf color of thymes during storage are shown in Table 2. The effect of storage time on the L* and $h^o$ value of thyme was significant, while there was no clear effect of both treatments and storage time on C* values ($P<0.05$). When all leaf color values at the beginning of storage were examined, it was observed that preharvest SA treatments gave better results compared to the control. The best results (L* = 45.61, C* = 29.66, $h^o$ = 114.17) were also obtained from $SA_{20}$ treatment at the end of storage.

**Table 2.** The effect of preharvest SA treatments on L*, C* and $h^o$ values of thyme during cold storage

| | L* | | | | | | |
|---|---|---|---|---|---|---|---|
| T | 0 | 5 | 10 | 15 | 20 | 25 | Avg. |
| C | 44.33 | 45.82 | 47.24 | 45.43 | 47.30 | 44.78 | $45.82^{NS}$ |
| $SA_{20}$ | 48.45 | 45.70 | 45.98 | 43.39 | 42.77 | 45.61 | 45.32 |
| $SA_{10}$ | 46.31 | 45.47 | 47.07 | 41.81 | 44.74 | 45.45 | 45.14 |
| Avg. | 46.36AB | 45.66AB | 46.76A | 43.54B | 44.94AB | 45.28AB | |
| | | | *SP* | | *T* | *SP × T* | |
| | | | * | | NS | NS | |

**Table 2.** The effect of preharvest SA treatments on L*, C* and h° values of thyme during cold storage (continued)

| C* | | | | | | | |
|---|---|---|---|---|---|---|---|
| T | 0 | 5 | 10 | 15 | 20 | 25 | Avg. |
| C | 26.83 | 29.08 | 28.23 | 27.05 | 30.04 | 28.68 | 28.32$^{NS}$ |
| $SA_{20}$ | 29.23 | 28.70 | 29.33 | 28.08 | 27.95 | 29.66 | 28.83 |
| $SA_{10}$ | 29.78 | 30.11 | 27.78 | 26.80 | 28.77 | 28.31 | 28.59 |
| Avg. | 28.61$^{NS}$ | 29.30 | 28.45 | 27.31 | 28.92 | 28.88 | |
| | | | *SP* | | *T* | *SP* × *T* | |
| | | | NS | | NS | NS | |
| h° | | | | | | | |
| T | 0 | 5 | 10 | 15 | 20 | 25 | Avg. |
| C | 113.92 | 114.24 | 113.72 | 113.83 | 113.17 | 113.43 | 113.72$^{NS}$ |
| $SA_{20}$ | 115.31 | 115.53 | 115.40 | 112.68 | 111.67 | 114.46 | 114.17 |
| $SA_{10}$ | 114.98 | 114.59 | 112.88 | 112.41 | 112.01 | 113.71 | 113.43 |
| Avg. | 114.73A | 114.78A | 114.00AB | 112.98AB | 112.28B | 113.86AB | |
| | | | *SP* | | *T* | *SP* × *T* | |
| | | | * | | NS | NS | |

The differences between the means in the same row and column indicated with different letters were statistically significant. ($P$<0.05). Avg.: Average, NS: Not Significant, T: Treatments, C: Control, SP: Storage period, SP×T: Interaction between storage period and treatments, $SA_{10}$: SA treatment 10 days before harvest, $SA_{20}$: SA treatment 20 days before harvest, *: $P$<0.05.

## Gas composition in MAP

**Table 3.** The effect of preharvest SA treatments on $O_2$ and $CO_2$ concentration in modified atmosphere bags during cold storage (%)

| $O_2$ | | | | | | | |
|---|---|---|---|---|---|---|---|
| T | 0 | 5 | 10 | 15 | 20 | 25 | Avg. |
| C | 20.90a | 18.75b | 16.13h | 17.88de | 17.03g | 18.73b | 18.23C |
| $SA_{20}$ | 20.90a | 20.70a | 17.17fg | 16.80g | 16.88g | 18.58b | 18.50B |
| $SA_{10}$ | 20.90a | 20.70a | 18.42bc | 17.68ef | 17.98cde | 18.35bcd | 19.00A |
| Avg. | 20.90A | 20.05B | 17.24D | 17.45D | 17.29D | 18.55C | |
| | | | *SP* | | *T* | *SP* × *T* | |
| | | | ** | | ** | ** | |
| $CO_2$ | | | | | | | |
| T | 0 | 5 | 10 | 15 | 20 | 25 | Avg. |
| C | 0.03ı | 5.90a | 5.55ab | 3.85fg | 4.20def | 2.90h | 3.73A |
| $SA_{20}$ | 0.03ı | 4.30def | 5.05bc | 4.68cd | 4.48cde | 3.20h | 3.62A |
| $SA_{10}$ | 0.03ı | 4.65cd | 4.27def | 4.03ef | 3.38gh | 3.35gh | 3.28B |
| Avg. | 0.03D | 4.95A | 4.95A | 4.18B | 4.01B | 3.15C | |
| | | | *SP* | | *T* | *SP* × *T* | |
| | | | ** | | * | ** | |

The differences between the means in the same row and column indicated with different letters were statistically significant. ($P$<0.05). Avg.: Average, T: Treatments, C: Control, SP: Storage period, SP×T: Interaction between storage period and treatments, $SA_{10}$: SA treatment 10 days before harvest, $SA_{20}$: SA treatment 20 days before harvest, *: $P$<0.05, **: $P$<0.01.

Changes in $O_2$ and $CO_2$ compositions in MAP are given in Table 3. The effects of SA treatments and storage periods on $O_2$ and $CO_2$ concentrations in MAP during cold storage were significant ($P$<0.05). Although there are fluctuations in the gas compositions in the bag during storage, depending on the respiration level of thyme and the gas permeability of the bag, decreases in $O_2$ concentration and increases in $CO_2$ concentrations were observed, in general. The lowest average $O_2$ value (18.23%) was determined in a control group, but the highest $O_2$ concentration (19.00%) was obtained from $SA_{10}$ treatment. On the other hand, it was determined that the $CO_2$ concentrations of SA-treated thymes ($SA_{10}$ and $SA_{20}$) were lower (3.28% and 3.62%, respectively) than the control (3.73%) group.

## Respiration rate and ethylene production

The changes in the respiration and ethylene production rates of thymes are given in Table 4. The effect of SA applications and storage time on respiration rate was statistically significant ($P<0.05$). Although the increases and decreases in respiration rates were observed during storage, in general, the main trend was a decrease. The average respiration rate value, which was measured as 217.60 mL $CO_2$ /kg.h at the beginning, was determined as 30.35 mL $CO_2$ /kg.h on the last day of cold storage. The lowest value of respiration was measured from $SA_{10}$ treatment (21.70 mL $CO_2$ /kg.h) followed by $SA_{20}$ (28.35 mL $CO_2$ /kg.h) at the end of storage.

The effect of storage time on ethylene production was significant. Although, in general, there were fluctuations in ethylene production rates, the main trend was a decrease similar to the respiration rate. The average ethylene production rate (4.63 $\mu LC_2H_4$ /kg.h) at the beginning decreased during storage and reached 0.89 $\mu LC_2H_4$ /kg.h at the end of storage. The lowest ethylene production value was measured from $SA_{10}$ treatment (1.90 $\mu LC_2H_4$ /kg.h) on the 25$^{th}$ day of storage.

**Table 4.** The effect of preharvest SA treatments on respiration rate (mL $CO_2$ /kg.h) and ethylene production of thyme ($\mu LC_2H_4$ /kg.h) during cold storage

| Respiration rate (mL $CO_2$ /kg.h) | | | | | | | |
|---|---|---|---|---|---|---|---|
| T | 0 | 5 | 10 | 15 | 20 | 25 | Avg. |
| C | 233.42 | 193.96 | 176.31 | 217.98 | 249.46 | 40.99 | 185.36A |
| $SA_{20}$ | 228.52 | 168.57 | 171.12 | 256.47 | 248.20 | 28.35 | 183.54A |
| $SA_{10}$ | 190.87 | 143.12 | 159.45 | 219.62 | 210.50 | 21.70 | 157.54B |
| Avg. | 217.60A | 168.55B | 168.96B | 231.36A | 236.05A | 30.35C | |
| | | | *SP* | | *T* | | *SP* × *T* |
| | | | ** | | ** | | NS |
| Ethylene production ($\mu LC_2H_4$ /kg.h) | | | | | | | |
| T | 0 | 5 | 10 | 15 | 20 | 25 | Avg. |
| C | 5.50 | 2.61 | 1.93 | 1.38 | 1.59 | 1.80 | 2.47$^{ÖD}$ |
| $SA_{20}$ | 5.12 | 1.72 | 1.24 | 2.48 | 1.48 | 0.48 | 2.09 |
| $SA_{10}$ | 3.28 | 2.04 | 2.20 | 2.19 | 1.29 | 0.40 | 1.90 |
| Avg. | 4.63A | 2.12B | 1.79B | 2.02B | 1.46BC | 0.89C | |
| | | | *SP* | | *T* | | *SP* × *T* |
| | | | ** | | NS | | NS |

The differences between the means in the same row and column indicated with different letters were statistically significant. ($P<0.05$). Avg.: Average, NS: Not Significant, T: Treatments, C: Control, SP: Storage period, SP×T: Interaction between storage period and treatments, $SA_{10}$: SA treatment 10 days before harvest, $SA_{20}$: SA treatment 20 days before harvest, *: $P<0.05$, **: $P<0.01$.

## Essential oil and carvacrol content

The change in essential oil and carvacrol contents are given in Table 5. The effect of SA treatments and storage period on the change in essential oil content during cold storage was not significant. The average essential oil content measured as 2.52% at the beginning was determined as 2.36% at the end of storage. The highest essential oil content was measured in $SA_{20}$ treatment at 2.58%, followed by $SA_{10}$ and control treatments at 2.25%, at the end of cold storage. The lowest change in essential oil content compared to the initial value was obtained from the $SA_{10}$ treatment (1.75%), followed by $SA_{20}$ (3.37%) and the control (12.1%) treatments.

The effect of storage time on carvacrol content during cold storage was significant. Although there was no statistical difference in terms of carvacrol content between SA-treated thymes and the control group, SA treatments showed a positive effect compared to the control group. The highest average carvacrol content was measured from the $SA_{10}$ treatment (49.65%), followed by $SA_{20}$ (48.51%) and control (44.95%).

**Table 5.** The effect of preharvest SA treatments on essential oil and carvacrol content of thyme during cold storage (%)

| Essential Oil | | | | | | | |
|---|---|---|---|---|---|---|---|
| T | 0 | 5 | 10 | 15 | 20 | 25 | Avg. |
| C | 2.56 | 2.55 | 2.92 | 2.67 | 2.51 | 2.25 | 2.58$^{NS}$ |
| $SA_{20}$ | 2.67 | 2.57 | 2.72 | 2.29 | 2.40 | 2.58 | 2.54 |
| $SA_{10}$ | 2.29 | 2.65 | 2.72 | 2.03 | 2.73 | 2.25 | 2.45 |
| Avg. | 2.52$^{NS}$ | 2.59 | 2.79 | 2.33 | 2.55 | 2.36 | |
| | | | *SP* | | *T* | | *SP* × *T* |
| | | | NS | | NS | | NS |
| Carvacrol Content | | | | | | | |
| T | 0 | 5 | 10 | 15 | 20 | 25 | Avg. |
| C | 42.82 | 45.32 | 47.74 | 37.98 | 54.84 | 40.97 | 44.95$^{NS}$ |
| $SA_{20}$ | 44.69 | 50.68 | 54.00 | 46.15 | 58.20 | 37.31 | 48.51 |
| $SA_{10}$ | 47.34 | 49.08 | 56.68 | 33.37 | 71.65 | 39.82 | 49.65 |
| Avg. | 44.95B | 48.36AB | 52.80AB | 39.17B | 61.56A | 39.37B | |
| | | | *SP* | | *T* | | *SP* × *T* |
| | | | ** | | NS | | NS |

The differences between the means in the same row and column indicated with different letters were statistically significant. ($P$<0.05). Avg.: Average, NS: Not Significant, T: Treatments, C: Control, SP: Storage period, SP×T: Interaction between storage period and treatments, $SA_{10}$: SA treatment 10 days before harvest, $SA_{20}$: SA treatment 20 days before harvest, **: $P$<0.01.

## Sensory analysis

The external appearance scores of thymes are given in Table 6. The effect of the storage period on external appearance scores was significant. The average external appearance score determined as 8.64 at the beginning was 5.04 on the last day of storage. On the 25$^{th}$ day of cold storage, the highest appearance score was measured at 5.22 from the $SA_{20}$ treatment, while control samples had the lowest score (4.83).

**Table 6.** The effect of preharvest SA treatments on external appearance scores of thyme during cold storage

| Storage period (day) | | | | | | | |
|---|---|---|---|---|---|---|---|
| T | 0 | 5 | 10 | 15 | 20 | 25 | Avg. |
| C | 8.77 | 8.55 | 7.94 | 7.83 | 6.44 | 4.83 | 7.39$^{NS}$ |
| $SA_{20}$ | 8.67 | 8.63 | 7.89 | 7.61 | 6.95 | 5.22 | 7.49 |
| $SA_{10}$ | 8.50 | 8.59 | 8.05 | 7.83 | 6.83 | 5.06 | 7.48 |
| Avg. | 8.64A | 8.59A | 7.96B | 7.76B | 6.74C | 5.04D | |
| | | | *SP* | | *T* | | *SP* × *T* |
| | | | ** | | NS | | NS |

The differences between the means in the same row and column indicated with different letters were statistically significant. ($P$<0.05). Avg.: Average, NS: Not Significant, T: Treatments, C: Control, SP: Storage period, SP×T: Interaction between storage period and treatments, $SA_{10}$: SA treatment 10 days before harvest, $SA_{20}$: SA treatment 20 days before harvest, **: $P$<0.01.

## Weight loss

Weight loss is an important parameter in the storage of fresh fruit and vegetables, as it refers to the reduction in the weight of the product to be marketed. Especially in leafy vegetables, as the weight loss increases depending on water loss, wrinkling and discoloration are observed in the product; thus, the external appearance is adversely affected. Similar to our study, it was reported that MAP + SA treatment had no effect on the weight loss of basil (Supapvanich et al., 2015). In this research, weight losses remained limited in all treatments during cold storage (Table1). This finding can be attributed to the effect of MAP, which limits water loss from the product. Likewise, Khan and Singh (2008) have stated that deterioration and water losses in products can be reduced by storage under MAP conditions.

**Leaf color**

Leaf color is one of the very important quality characteristics for fruit and vegetables, and it affects the market value of the products and the preference of the consumer. Color change, which is one of the important factors limiting the postharvest life of vegetables, may be caused mostly by enzymatic browning and pigment degradation (Cantwell & Reid, 1993). In the present study, although the L* values, which express the brightness on the leaf surface, fluctuated during storage, these values of the SA-treated thymes remained partially higher than those of the control group at the end of storage (Table 2). These findings show that SA treatments have a partial positive effect on the brightness of leaf color. Likewise, Koyuncu et al. (2018), reported that SA better preserved the color brightness of dill at the end of storage.

The highest C* value, which expresses the color intensity or vividity, was determined from $SA_{20}$ treatment at the end of storage (Table 2). In studies conducted in previous years, it has been reported that SA treatments delay color change (Cao et al., 2013) and slow down the loss of vividity of color that occurs in parallel with senescence (Asghari & Aghdam, 2010). The hue angle value expresses the color perceived by the eye and indicates that the color is green at 180°. The highest $h^o$ value was determined from $SA_{20}$ treatment (Table 2). Supapvanich et al. (2015) indicated that preharvest SA treatment was effective in preserving the leaf color of lemon basil. Similarly, postharvest SA treatments have been reported to have a positive effect on the color of asparagus (Wei et al., 2011).

**Gas composition in MAP**

While the average $O_2$ concentration was 20.05% on the $5^{th}$ day of storage, it decreased to 18.55% on the $25^{th}$ day. On the other hand, it was determined that the $CO_2$ concentration in MAP containing SA-applied thymes ($SA_{10}$) was lower than in control samples (Table 3). This shows that SA treatments, especially $SA_{10}$, slowed down the respiration rate of thymes compared to control samples. We can explain this effect of SA with its suppression of ethylene synthesis (Huang et al., 1993), reduction in respiration rate by closing stomata in plants (Manthe et al., 1992), and delaying senescence by reducing metabolic activity (Wills et al., 1981). Similar to the findings of the present study, Sakaldaş et al. (2010) reported that the $O_2$ concentration in MAP decreased while the $CO_2$ concentration increased as the storage time increased.

**Respiration rate and ethylene production**

The postharvest respiration rate of leafy edible vegetables is an important indicator that implies the metabolic activity of those products. The factors that decrease the respiration rate delay the senescence and quality losses of fresh products and extend their postharvest life (Özen et al., 2021). In the present study, decreases were observed in the respiration rates of thyme during storage (Table 4). But a clear reduction in the respiration rates of all treatments on the 25th day of storage can be explained by the senescence of thyme samples. On the other hand, the decrease in respiration rate can be attributed to the fact that MAP treatments suppress the respiration of fruit and vegetables. In passive MAP treatments, a certain period of time must pass in order to decrease $O_2$ and to increase $CO_2$ concentration in the package depending on the respiration rate and weight of the product. Similarly, it has been reported that the respiration rates of fruit stored in MAP decrease depending on low $O_2$ and high $CO_2$ concentrations (Üçüncü, 2011). Martinez-Espla et al. (2018) also stated that preharvest SA treatments suppressed the respiration of different crops in cold storage. SA treatments are thought to delay the senescence of thymes during the postharvest period. Likewise, Wills et al. (1981) indicated that SA

treatments effectively delay the senescence processes of fruit and vegetables by reducing metabolic activity and water loss.

In general, thyme samples in the control group produced higher ethylene during storage (Table 4). It is thought that the low level of ethylene production in SA-treated thymes is due to slowing down the metabolic processes of thyme with SA treatment. Similarly, it has been reported that SA prevents the formation of ACC, the precursor of ethylene, or its conversion to ethylene (Huang et al., 1993). As expected, decreasing ethylene production through SA application was similar to the change in respiration rate. These data support the results obtained from both the gas composition in MAP and respiration rate sections in this study (Tables 3 and 4).

**Essential oil and carvacrol content**

It is known that effective substances obtained from aromatic plants consist of essential oils. The lowest essential oil change during storage was obtained from SA10 treatment (Table 5). It can be indicated that preharvest SA treatments have a positive effect on the change of essential oil content during cold storage. In similar studies, it has been reported that preharvest SA treatments are effective in maintaining the essential oil content in mint (Saharkhiz & Goudarzi, 2014; Curutchet et al., 2014).

The essential oil obtained from the thyme (*Origanum onites* L.) plant differs from other plants with its high carvacrol content, which is a component of biological importance (Kirimer et al., 1995). Carvacrol is a phenolic monoterpenoid found in essential oils of plants such as thyme, black pepper, and wild bergamot. In the present study, preharvest SA treatments have a partially positive effect on the carvacrol content of thyme at harvest (Table 5). This positive effect can be explained by the effect of SA on the metabolic activity and enzymes responsible for the biosynthesis of mono - and sesquiterpenes (Rowshan et al., 2010). The average carvacrol contents of SA-treated thymes were higher compared with the control group, though this difference was not statistically significant (Table 5). On the other hand, it has been reported in similar studies that there may be increases in important essential oil components after cold storage in some horticultural products (Morales et al., 2014; Zhao et al., 2019).

**Sensory analysis**

The external appearance is one of the most critical factors affecting the consumer's choice while purchasing the product. A pleasing appearance, especially in edible vegetables, is accepted by consumers as an indicator indicating the product's freshness. External appearance and taste, among the critical quality parameters of fresh products, are negatively affected as the storage time increases. Likewise, in the current study, external appearance scores decreased parallel to the storage period. According to the external appearance scale at the end of storage, the $SA_{20}$ and $SA_{10}$ treated thymes with a score above 5 were marketable, whereas the control samples were unmarketable (Table 6). SA treatments positively affect the sensory quality of thyme. This positive effect can be explained by the fact that SA slows down metabolic activities and has antimicrobial properties (Wills et al., 1981). Similarly, studies with different horticultural products have reported that SA positively affects the external appearance of edible vegetables (Able et al., 2005; Koyuncu et al., 2018).

## CONCLUSION

Weight loss of thymes increased steadily in all treatments, but SA did not positively affect weight loss. Thymes' initial respiration rate values were suppressed over time with the effect of treatments and storage conditions. SA-treated thymes, in general, had lower ethylene production rates during storage compared to the control group, though this difference was not statistically significant. Although the effects of the treatments on the carvacrol content of thyme were statistically insignificant, the average

carvacrol contents obtained from SA-treated thymes were relatively higher than those of the control group.

The marketable quality of thymes (above 5.0 points), except for control samples, was maintained until the end of storage. However, there was a rapid decrease in the external appearance scores in all treatments after the 15th day of storage. As a result, thyme treated with 1.5 mM SA 10 days before harvest could be stored for 15 days in MAP at 1°C and 90 ± 3% relative humidity.

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### Conflict of Interest

The article authors declare that there is no conflict of interest between them.

### Author's Contributions

The authors declare that they have contributed equally to the article.

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