

8-22-2025

Effects of storage temperatures on quality and phytochemical properties of the hawthorn (*Crataegus azarolus* L.) during storage and shelf life

AHMET ERHAN ÖZDEMİR

OĞUZHAN ÇALIŞKAN

SAFDER BAYAZIT

KAZİM GÜNDÜZ

NURDAN TUNA GÜNEŞ

See next page for additional authors

Follow this and additional works at: <https://journals.tubitak.gov.tr/agriculture>



Part of the [Agriculture Commons](#), and the [Forest Sciences Commons](#)

Recommended Citation

ÖZDEMİR, A. E, ÇALIŞKAN, O, BAYAZIT, S, GÜNDÜZ, K, TUNA GÜNEŞ, N, KARASHAHİN, Z, KILIÇ, D, & KARAHAN, R. B (2025). Effects of storage temperatures on quality and phytochemical properties of the hawthorn (*Crataegus azarolus* L.) during storage and shelf life. *Turkish Journal of Agriculture and Forestry* 49 (4): 703-718. <https://doi.org/10.55730/1300-011X.3298>



This work is licensed under a [Creative Commons Attribution 4.0 International License](#).

This Research Article is brought to you for free and open access by TÜBİTAK Academic Journals. It has been accepted for inclusion in Turkish Journal of Agriculture and Forestry by an authorized editor of TÜBİTAK Academic Journals. For more information, please contact academic.publications@tubitak.gov.tr

Effects of storage temperatures on quality and phytochemical properties of the hawthorn (*Crataegus azarolus* L.) during storage and shelf life

Authors

AHMET ERHAN ÖZDEMİR, OĞUZHAN ÇALIŞKAN, SAFDER BAYAZIT, KAZİM GÜNDÜZ, NURDAN TUNA GÜNEŞ, ZAFER KARAŞAHİN, DERYA KILIÇ, and RAMAZAN BESTAMİ KARAHAN

Effects of storage temperatures on quality and phytochemical properties of the hawthorn (*Crataegus azarolus* L.) during storage and shelf life

Ahmet Erhan ÖZDEMİR¹, Oğuzhan ÇALIŞKAN^{1*}, Safder BAYAZIT¹, Kazim GÜNDÜZ², Nurdan TUNA GÜNEŞ³, Zafer KARAŞAHİN⁴, Derya KILIÇ¹, Ramazan Bestami KARAHAN⁵

¹Department of Horticulture, Faculty of Agriculture, Hatay Mustafa Kemal University, Hatay, Türkiye

²Department of Horticulture, Faculty of Agriculture, Malatya Turgut Özal University, Malatya, Türkiye

³Department of Horticulture, Faculty of Agriculture, Ankara University, Ankara, Türkiye

⁴Alata Horticultural Research Institute, Ministry of Agriculture and Forestry, Mersin, Türkiye

⁵Nuts Research Institute, Ministry of Agriculture and Forestry, Adıyaman, Türkiye

Received: 19.12.2023

Accepted/Published Online: 20.02.2025

Final Version: 22.08.2025

Abstract: This study aimed to investigate the effects of storage temperature on the quality and phytochemical characteristics in Sultan hawthorn cultivar during cold storage and shelf life. Fruits were stored at 0 ± 0.5 °C and 4 ± 0.5 °C and $90 \pm 5\%$ relative humidity (RH) for 6 months in cold storage and were analyzed every month. In addition, hawthorn fruits were kept at 20 ± 0.5 °C and $75 \pm 5\%$ RH for 7 days, and their shelf life was investigated at monthly intervals. Weight loss, appearance, the incidence of physiological disorders and fungal decay, fruit skin color, firmness, total soluble solids (TSS) content, titratable acidity (TA), TSS/TA ratio, pH, sensory evaluation, vitamin C, sugar profile (glucose, fructose, and sucrose), total antioxidant scavenging capacity, total phenolics, total flavonoids, and total anthocyanins were determined during storage and shelf life. According to the results, firmness was the most prominent criterion in determining the harvest time. The second week of September was determined as the optimum harvest time for the Sultan hawthorn cultivar. Weight loss during storage was higher at 4 °C (14.34%) compared to 0 °C (9.07%). The results showed that this cultivar can retain most of the fruit quality and phytochemical attributes when stored at 4 °C and 85-90% RH for 3 months, and 0 °C and 85-90% RH for 4 months. Further studies are required to expand our knowledge of sophisticated techniques to maintain the fruit quality of hawthorn during long-term storage.

Key words: Firmness, phenolics, sugar, vitamin C

1. Introduction

Hawthorn is systematically included in the *Crataegus* genus of the Maloideae subfamily, of the Rosaceae family (Ağaoğlu et al., 2001). Hawthorn fruits have health benefits such as lowering cholesterol and reducing the risk of heart disease, angina, and vascular system diseases (Karadeniz, 2004; Ayanoglu et al., 2023). In addition, hawthorn fruit contains very high amounts of mineral substances, especially calcium, phosphorus, potassium, magnesium, and iron (Özcan et al., 2005). Hawthorn fruit contains a large number of organic acids such as citric, malic, and succinic acids, and phenolics such as catechin, chlorogenic, and caffeic acids (Gundogdu et al., 2014; Gurlen et al., 2020), and mainly butyl hexanoate and hexyl hexanoate esters as volatile compounds at the ripening stage (Dursun et al., 2021). Their high phenolic and antioxidant capacity has also led to an increase in hawthorn usage area in the processing industry (Ercisli et al., 2015).

More than 30 hawthorn species have been identified in Türkiye. The most common species globally and in Türkiye is *Crataegus monogyna* followed by *Crataegus azarolus* L. and *Crataegus orientalis*. In recent years, *C. azarolus* genotypes have become widespread due to the larger fruit size and better fruit quality compared to the others (Dönmez, 2007; Yilmaz et al., 2010; Çalışkan et al., 2022). In addition, the fruit of hawthorn cultivars belonging to *Crataegus pinnatifida* in China (Chang et al., 2006), *Crataegus mexicana* in Mexico (Velasco-Hernández et al., 2017), and *Crataegus aestivalis*, *Crataegus opaca*, and *Crataegus rufula* in the United States (Payne and Krewer, 1990; Trappey et al., 2008) are widely consumed as fresh, dried, and processed products.

There are limited studies on the storage conditions of cultivated and wild forms of hawthorn fruit. Chang et al. (2006) reported that storing the dried fruit of *C. pinnatifida* 'Major' at 4 °C for 6 months offered very promising results.

* Correspondence: ocaliskan@mku.edu.tr

Šamec and Piljac-Žegarac (2011) investigated the effect of storage temperature on the phytochemical content of *C. monogyna* fruit and did not observe a negative effect of storage at 4 °C compared to 25 °C. According to Velasco-Hernández et al. (2017), the fruits of *C. mexicana* did not show a climacteric pattern when they were kept at 20 ± 2 °C for 8 days without a change in sugar and acid content; however, 13% weight loss occurred at the end of the eighth day. Also, Ávila-Sosa et al. (2017) suggest that weak blue and UV-C light waves could be an appropriate way to improve hawthorn phytochemical profiles during storage at room temperature (18–22 °C) for 30 days.

Currently, hawthorn genotypes of *C. azarolus* are grown as a minor fruit in Türkiye. In Hatay, located in the Eastern Mediterranean region, *C. azarolus* Sultan has been commercially grown for 30 years. The fruit of this cultivar is the largest and has a sweet and sour flavor widely preferred by consumers. The prices are high at 5–6 USD per kilogram in Türkiye (Çalışkan et al., 2018). The high market value has encouraged growers to set modern orchards with this cultivar in different regions of Türkiye, especially in the East Mediterranean Region. However, no information on the storage conditions and shelf life of this cultivar has been reported so far. Therefore, the main question of the study is: What is the effect of storage temperature on changes in the quality traits and biochemical content of hawthorn fruit during the postharvest period? The main aim of this study is to investigate the effects of different storage temperatures on fruit quality and some phytochemical properties of the Sultan hawthorn cultivar fruit during storage and different shelf-life periods. These results could significantly contribute to further studies on the cold storage and shelf life of hawthorn fruit.

2. Materials and methods

2.1. Plant material

This study was conducted between August 2018 and February 2019. In this study, the fruit of the Sultan hawthorn cultivar was obtained from 30-year-old trees grafted on

seedling rootstocks grown in a commercial hawthorn orchard in Belen district (36°43'09"N, 36°13'80"E, and altitude 812 m) in Hatay Province, Türkiye. These trees were planted in 5 m × 5 m spacing and pruned with an open vase system. This location has typical Mediterranean ecological conditions with hot, dry summers and mild, rainy winters. The soil texture of the orchard was loam-clay and slightly alkaline. All cultural practices such as irrigation, fertilization, control of pests and diseases were standardly performed in the orchard. The full bloom period occurred between April 20 and April 26, 2018. The fruit of the Sultan hawthorn cultivar has yellow skin color, on average 15.03 g in fruit weight, 32.03 mm in width, and 26.88 mm in length. The average seed number is 2.40 and the total content of soluble solids is 15.00% (Çalışkan et al., 2018) (Figure 1).

2.2. Harvest and storage

During the preharvest period, fruit samples were sampled in 2018 on August 29, September 05, and September 14 to determine the optimum harvest date. For this purpose, fruit samples were collected based on the presence of at least 15% total soluble solids (TSS) content in the juice, as reported by Dursun et al. (2021). In this period, fruit weight, fruit width and length, appearance, TSS content percentage, titratable acidity (TA) content percentage, TSS/TA ratio, pH, and taste were analyzed to determine the optimal harvest time. These analyses were carried out with three replicates and 25 fruits in each replicate. A total of 75 fruits were used during the sampling period.

Harvested fruit were transported within 30 min in 12 kg crates to the cold storage facility of the Department of Horticulture, Hatay Mustafa Kemal University. The fruits with uniform size, color, and free from defects such as growth cracks, bruises, and decay were selected for use in the study.

Fruits were packaged in 500 g punnets with 20 holes with 2% ventilation in total. They were stored for 5 months at two different temperatures (0 ± 0.5 °C and 4 ± 0.5 °C) at $90 \pm 5\%$ relative humidity (RH) conditions. After the cold



Figure 1. The appearance of Sultan hawthorn fruit at the beginning of the storage period and harvest time.

storage, the fruits were kept at 20 ± 0.5 °C and $75 \pm 5\%$ RH for 7 days for shelf-life observations.

Monitoring of fruit quality during the preharvest period to determine optimum harvest time was performed at weekly intervals. During the cold storage period, the fruit was sampled at monthly intervals and after 7 days during shelf-life storage.

2.3. Assessments

The fruit weight was measured with a balance (Ohaus Adventurer, Parsippany, NJ, USA) with 0.01 g sensitivity. Fruit width and height were measured in mm by a digital caliper (Mitutoyo, Kawasaki, Japan) with 0.01 mm sensitivity. Fruit width was determined at the widest equatorial section of fruit. Fruit height was measured between fruit stem and blossom end.

During the storage period, weight loss was determined by weighing relative to the beginning fruit weight and was expressed as a percentage.

The rate of fungal decay was determined by counting the number of fruits that had visible fungal growth and expressed as a percentage of all fruits in each replication. For physiological disorders, the fruits were checked monthly in the storage period and after the shelf-life period. The rate of disorders was calculated as a percentage of all fruit in each replication.

Fruit skin color was measured with the Minolta CR-300 Chromometer (Konica Minolta Sensing Inc., Osaka, Japan) using the International Commission on Illumination (CIE) (L^* , a^* , b^*) color space system on two opposite sides of the equatorial region of fruit. The measures used were L^* (lightness), chroma (C^*), and hue (h°) values (McGuire, 1992).

The fruit flesh firmness was determined by a penetrometer (Effegi model FT 327, QA Supplies, USA) with a probe diameter of 7.9 mm. Readings were taken in kg and the results were presented as Newton (N).

TSS content was measured by a digital refractometer (Atago PAL-1, Japan) in squeezed fruit juice. TA was determined by titration (Brand Titrette, Brand GmbH + Co KG, Wertheim, Germany) of fruit juice with 0.1 N NaOH until pH equaled 8.10. The results were presented as the percentage of malic acid (Çalışkan et al., 2018). The TSS/TA ratio was periodically calculated by dividing TSS by TA for each replication at each time point. The pH of juice was measured by a digital pH meter (HI 2211 pH/ORP meter, Hanna Instruments, Woonsocket, RI, USA).

Sensory evaluation data were recorded using appearance and fruit taste. Both measures were evaluated by ten trained panelists (seven males and three females, aged from 20 to 45, all nonsmokers). Fruit appearance was evaluated on a scale of 1-5 points (1 = very poor, 2 = poor, 3 = fair, 4 = high, and 5 = very high) based on the attractiveness of the fruit. Fruit taste was evaluated

on a scale of 1-9 points (1 = disliked to 9 = liked) taking into account sweet, sour, astringency, and juiciness. The appearance and taste scores >3 and >5 were considered as acceptable quality, respectively, during preharvest, cold storage, and shelf-life periods.

Sugar analysis was performed in homogenized frozen hawthorn fruit juice samples. The extractions were performed as described by Bartolomé et al. (1995). For this purpose, fruit juice was diluted by 50% and passed through a membrane filter with a $0.45 \mu\text{m}$ pore diameter, then analyzed via a high-performance liquid chromatography (HPLC) system (Shimadzu LC20AD, Tokyo, Japan) fitted with a refractive index detector. During the separation of sugar, the mobile phase included acetonitrile and double deionized water (DDW) in a 80:20 ratio (v/v) and was applied at a flow rate of 1.3 mL min^{-1} . The column (Inertsil NH_2 , GL Sciences, Tokyo, Japan) temperature was set as 30 °C. Quantification was performed based on external standards obtained from Sigma-Aldrich (Darmstadt, Germany). The results were expressed as grams per 100 mL^{-1} of fruit juice.

Health properties of hawthorn fruit, including vitamin C, total antioxidant scavenging capacity (TAC), total phenolics (TPs), total flavonoids (TFs), and total anthocyanins (TAn) were investigated in this study. Vitamin C (L-Ascorbic acid) content was detected as in Cemeroglu (2007). Briefly, 5 mL of fruit juice was combined with 5 mL of 6% metaphosphoric acid solution and centrifuged at 6500 rpm for 10 min at 4 °C. The mixture was filtered through a Teflon filter with a $0.45 \mu\text{m}$ pore size and then a 20 μL sample was analyzed via HPLC (Shimadzu LC20AD, Tokyo, Japan) system. The separation was carried out on a PDA (diode array detector) and an Inerstil ODS-3 column ($4.6 \text{ mm} \times 250 \text{ mm}$, $5 \mu\text{m}$; GL Sciences). L-ascorbic acid solutions at different concentrations were used as an external standard and the results were expressed as milligrams per 100 mL^{-1} of fruit juice.

The TAC was analyzed according to Klimczak et al. (2007). Fruit juices were centrifuged at 4000 rpm for 20 min at 4 °C. Five milliliters of the centrifuged juice sample was transferred into a centrifuge tube and mixed with 5 mL of DDW by vortexing. Then, 2.46 mL of 1,1-diphenyl-2-picrylhydrazyl (DPPH, 0.025 g L^{-1} in 50% ethanol) was added to a 100 μL of the juice sample. The absorbance value of the samples was measured at 515 nm in a spectrophotometer (BioTek PowerWave HT, BioTek Instruments, Winooski, VT, USA) at 5, 10, 30, 45, and 60 min. The measurement at 60 min was used. The TAC activity was expressed as millimole Trolox equivalent (TE) L^{-1} fruit juice inhibition of DPPH.

The TPs were determined using Folin-Ciocalteu reagent as reported by Abdullakasim et al. (2007). Briefly, 5 mL of fruit juice was mixed with 5 mL of methanol

solution (80%) and dilution was made with methanol solution (80%) to a suitable ratio and centrifuged at 4 °C and 4000 rpm for 20 min. Then, 100 µL of Folin-Ciocalteu reagent was added to 100 µL and 3000 µL of DDW. It was kept at room temperature for 10 min. After that, 100 µL of 20% Na₂CO₃ solution was added and left in the dark for 2 h. The absorbance value was measured at 765 nm in a spectrophotometer (BioTek PowerWave HT). The results were expressed as milligrams GAE (gallic acid equivalent) per 100 mL⁻¹ of fruit juice.

For the TF analyses, 1 mL of the juice sample was transferred into a test tube with 4 mL of DDW. Then, 0.3 mL of 5% sodium nitrite (NaNO₂) at 0 min, 0.3 mL of 10% aluminum chloride (AlCl₃) at 5 min, 2 mL of 1 M NaOH at 6 min, and then 2.4 mL of DDW was added for a final volume of 10 mL. The absorbance value of the mixed sample was recorded at 510 nm in a spectrophotometer (BioTek PowerWave HT) and the results were expressed as milligrams catechin equivalent (CE) per 100 mL⁻¹ of fruit juice (Zhishen et al., 1999).

To determine the TAn content, 1 mL of the juice sample was combined with 24 mL of 0.025 M potassium chloride (KCl) solution with a pH value of 1.0. In addition, 1 mL of the juice sample was mixed with 24 mL of 0.4 M sodium acetate solution with a pH value of 4.5. The absorbance readings of the samples were obtained at 520 nm and 700 nm for the two buffer systems, respectively, using a spectrophotometer (BioTek PowerWave HT). The results were expressed as milligrams of cyanidin-3-glycoside (cy-3-gluc) per 100 mL⁻¹ of fruit juice (Giusti and Wrolstad, 2001).

2.4. Experimental design and statistical analysis

All analyses to determine fruit quality characteristics were conducted on 500 g punnets in each replication with monthly intervals during the cold storage and shelf-life periods. This experiment was set as a completely randomized plot design with three replications. Different storage temperatures, cold storage, and shelf-life periods were factors of the experiment. Analysis of variance (ANOVA) was performed on the data using statistical software SAS version 9.4 (SAS, 2019). Tukey's HSD posthoc tests at $p < 0.05$ level were performed using the SAS Proc GLM procedure. Arcsin transformations were applied to the percentage data before statistical analysis.

3. Results and discussion

3.1. Changes during the preharvest period

During the preharvest period, only the flesh firmness and fruit taste scores changed significantly depending on the sampling times (Table 1 and Figure 2). In this period, fruit weight ranged between 15.77 and 16.14 g, fruit width ranged between 31.47 and 33.09 mm, and fruit length ranged between 26.66 and 27.80 mm. The average flesh firmness was 39.13 N at the first sampling date and significantly decreased to 30.24 N at the third date. In the panelist observations, the appearance scores were above 3 points, meaning they were at an acceptable level in all sampling periods. At later sampling dates, fruit taste significantly increased with >8 points at the last two sampling dates (Figure 2). TSS content varied between 14.89% and 15.98%, TA between 2.07% and 2.10%, TSS/TA ratios between 7.19 and 7.72, and pH between 3.20

Table 1. Physical and chemical changes in Sultan hawthorn cultivar fruit during the preharvest period at different sampling times.

Sampling time	Physical assessments			
	Fruit weight (g)	Fruit width (mm)	Fruit height (mm)	Flesh firmness (N)
August 29, 2018	15.96	31.69	27.80	39.13 a
September 5, 2018	16.14	31.47	26.66	36.85 b
September 14, 2018	15.77	33.09	27.27	30.24 c
HSD (5%)	NS	NS	NS	4.31
Sampling time	Chemical assessments			
	TSS (%)	TA (malic acid %)	TSS/TA	pH
August 29, 2018	15.15	2.10	7.21	3.20
September 5, 2018	15.98	2.07	7.72	3.28
September 14, 2018	14.89	2.07	7.19	3.31
HSD (5%)	NS	NS	NS	NS

Different letters within columns indicate significant differences by Tukey's HSD test at $p < 0.05$. NS: nonsignificant; TSS: total soluble solids, TA: titratable acidity.

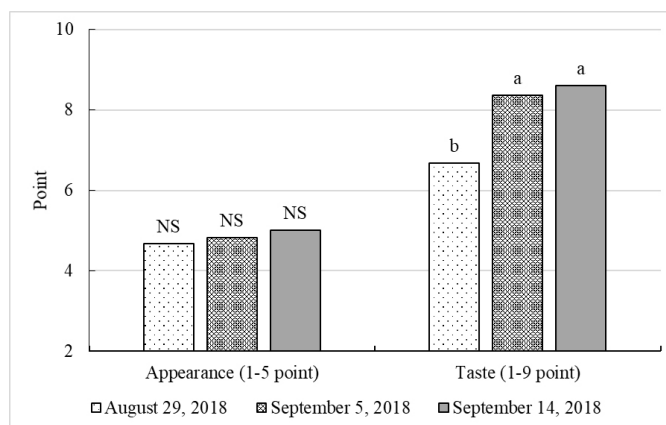


Figure 2. Sensory evaluation points in Sultan hawthorn cultivar fruit during the preharvest period at different sampling times. NS: nonsignificant. Different letters columns indicate significant differences by Tukey's HSD test at $p < 0.05$.

and 3.31. However, changes in these parameters were not significant (Table 1).

Fruit maturity at harvest time is an important factor for the long-term storage and marketing life of fruit (Özdemir et al., 2021). Also, Erkan and Pekmezci (2004) indicated that different physiological problems, such as superficial scald, may occur in the fruit during storage after early harvest in apples. Our results showed that the most prominent harvest time criterion in the Sultan hawthorn cultivar fruit was flesh firmness. In the current study, the second week of September was the optimal harvest time. Harvesting at this time allows for the desired commercial maturity and quality, with firmness about 30 N, TSS above 15%, TA over 2%, TSS/TA ratio above 7.1, fruit weight above 15 g, and fruit width and length above 30 mm.

3.2. Postharvest fruit characteristics of Sultan hawthorn cultivar fruit under different temperature regimes

Before the experiment began, the storage period at different temperatures was planned for 6 months. However, excessive rotting at 0 °C and 4 °C, and excessive deterioration and shriveling of fruit at 4 °C limited the storage period to 5 months (Figures 3 and 4).

Weight loss significantly increased with a prolonged cold storage period and reached 15.82% at the end of 5 months. Fruit stored at 4 °C had significantly higher weight loss than at 0 °C (14.34% and 9.07%, respectively) during the cold storage period. There was a lot of shriveling due to weight loss at 4 °C (Figure 4). The effect of the cold storage temperatures on weight loss was not significant during the shelf-life period (Table 2). Weight loss in hawthorns is higher than in other fruits due to their low skin diffusion resistance. Water loss constitutes the most important part of weight loss and is one of the critical parameters restricting the storage life of fruit (Özkaya et al., 2005).

The vapor pressure difference between the product and its surrounding atmosphere is a driving force for evaporation. When the RH is kept constant, the vapor pressure difference increases with the increase in temperature. Therefore, it is expected that weight loss is higher at high temperatures (Özdemir et al., 2008). In general, 10% of weight loss has been a commercially acceptable limit for fruit to become marketable. Also, visible shriveling symptoms in the fruit of many species become noticeable when the weight loss exceeds 5% (Elyatem and Kader, 1984; Karaçalı, 2009). Unlike many other fruit species, no visible shriveling symptoms were observed on the fruit of the Sultan hawthorn cultivar since weight loss was below 15%–17% for the attraction and consumer acceptability of the fruit. Similarly, Velasco-Hernández et al. (2017) reported a 13% weight loss of *C. mexicana* after eight days of shelf life, which reduced marketable fruit quality. Zandi et al. (2020) reported that 35.11% of the weight loss in hawthorn fruit was evident after 20 days at room conditions (25 °C and 60% RH), 26.11% in the refrigerator (10 °C and 85% RH), and 19.17% in cold storage (1 °C and 90% RH). In addition, Ozturk et al. (2020) indicated that acceleration of oxidation after physical injury and increased respiration rate may also cause weight loss in stored fruit.

Fungal decays caused mostly by *Penicillium digitatum*, *Penicillium italicum*, *Botrytis* and *Alternaria* were detected in the fruit of the Sultan hawthorn cultivar during cold storage at two temperatures and the shelf-life period after the cold storage period (Table 2). Moreover, after 6 months of cold storage and shelf life, the incidence of fungal decay was severe (Figure 3). Fungal decay was detected only at 4 months during the cold storage at both temperatures. The effects of storage time and temperature on fungal decay were not significant. Fungal decay was only observed at an



Figure 3. Fungal deterioration of the fruits of the Sultan hawthorn cultivar in 6 months at 0 and 4 °C.



Figure 4. Shriveling of the Sultan hawthorn fruits in 6 months at 4 °C.

average of 3.24% at the end of the shelf-life period after 5 months of the cold storage period.

During the storage and shelf-life period, the most observed physiological disorders were brown pitting, a small amount of cracking of the fruit skin due to senescence, and brownish spots on the fruit skin (Figure 5). Physiological disorders were observed in an average of only 0.37% of the samples after 5 months at 0 °C. However, the effects of storage period and storage temperature on physiological disorders were not statistically significant. Physiological disorders were only observed at an average

of 7.69% at the end of the 7-day shelf-life period after a storage period of 5 months (Table 2). In storage at low temperature, hawthorn fruit may be developing visually pitting as a physiological symptom of chilling injury. Also, cracking and brownish spots on the fruit skin after the 5 months and 7 days were observed due to a low amount of senescence. Similarly, Razavi et al. (2018) reported that approximately 35% of pitting as a symptom of chilling injury in hawthorn fruit was shown during a 3-day shelf-life period following 20 days of cold storage at 1 °C. Aghdam et al. (2018) reported that postharvest, 1.5 mM



Figure 5. The physiological disorders on the Sultan hawthorn fruit determined at 5 months of storage at 0 °C. Top: pitting, bottom left: brownish spots on the fruit skin, and bottom right: cracking in the fruit skin.

Table 2. The effect of different storage temperatures, cold storage, and shelf-life periods on weight loss, rate of fungal decay, and physiological disorders of Sultan hawthorn fruit.

Effects	Weight loss (%)	Fungal decay (%)	Physiological disorders (%)
Storage temperatures during cold storage			
0 °C	9.07 b	0.37	0.26
4 °C	14.34 a	0.00	0.00
HSD (5%)	1.39	NS	NS
Cold storage period (months)			
0	---	---	---
1	5.90 c	0.00	0.00
2	9.94 b	0.00	0.00
3	12.63 ab	0.00	0.00
4	14.22 a	1.10	0.00
5	15.82 a	0.00	0.79
HSD (5%)	3.61	NS	NS
Storage temperatures during shelf life			
0 °C	3.56	0.37	2.56
4 °C	4.72	0.71	0.00
HSD (5%)	NS	NS	NS
Shelf life (month + day)			
0 + 7	2.53	0.00 b	0.00 b
1 + 7	3.65	0.00 b	0.00 b
2 + 7	5.10	0.00 b	0.00 b
3 + 7	5.13	0.00 b	0.00 b
4 + 7	5.10	0.00 b	0.00 b
5 + 7	3.35	3.24 a	7.69 a
HSD (5%)	NS	2.75	6.87

Different letters within columns indicate significant differences by Tukey's HSD test at $p < 0.05$. NS: nonsignificant.

NaHS can be applied to hawthorn fruit to improve chilling tolerance by increasing enzyme activity and phenolics. However, peel pitting is affected by preharvest irrigation and precipitation that affects the water content of the fruit, as well as the transfer of moisture during storage at nonchilling temperatures (Alferez and Burns, 2004).

Fruit skin brightness (L^*) of the Sultan hawthorn cultivar fruit decreased during cold storage and shelf life (Table 3). The average initial fruit skin color L^* value was 82.12. It decreased to 78.13 at the end of 5 months. Fruit stored at 4 °C had a higher fruit skin color L^* value than those at 0 °C (80.22 and 79.30, respectively) during the storage period. During the 7-day shelf-life period, the average initial fruit skin color L^* value was 79.89 and it decreased to 77.76. Fruit stored at 4 °C had a higher fruit skin color L^* value compared to 0 °C (79.04 and 78.31, respectively) during shelf life. Similar to these results, Velasco-Hernández et al. (2017) observed a decrease in the fruit skin color L^* values in *C. mexicana*, which indicates loss of brightness in the fruit of this species during the 8-day shelf life. Moreover, brightness loss is usually due

to physiological disturbances, especially brown pitting and skin browning in hawthorn fruit. This could be due to water loss during storage. Also, Zandi et al. (2020) reported a decrease in the fruit skin color L^* values over 20 days under room conditions, refrigerator, and cold storage in hawthorn. Similarly, fruit skin color brightness decreased in apple (Kovač et al., 2010) and kiwifruit (Öztürk and Yücedağ, 2021) depending on the storage period.

The fruit skin C^* value of Sultan hawthorn fruit, increased from 46.93 at in cold storage at different temperatures to 48.63 at the end of 5 months of storage. This means that fruit color becomes more saturated during the cold storage period. The fruit skin C^* value was higher in those stored at 4 °C than in those stored at 0 °C (47.24 and 45.96, respectively). While the average fruit skin C^* value was 47.45 at the end of the first shelf-life period, this value showed fluctuations and increased to 48.08 at 5 months and 7 days. The effect of storage temperatures on the fruit skin C^* value during shelf life did not show significant differences (Table 3). Similar to our results, Zandi et al. (2020) reported that there was an increase

Table 3. The effect of different storage temperatures, cold storage, and shelf-life periods on chromaticity values of Sultan hawthorn fruit.

Effects	L^*	C^*	h°
Storage temperatures during cold storage			
0 °C	79.30 b	45.95 b	98.59
4 °C	80.22 a	47.24 a	98.42
HSD (5%)	0.82	0.80	NS
Cold storage period (months)			
0	82.12 a	46.93 abc	99.58 a
1	80.94 a	46.34 bcd	99.40 ab
2	79.06 b	45.47 cd	98.96 ab
3	80.12 a	44.57 d	99.92 a
4	78.21 b	47.65 ab	96.99 bc
5	78.13 b	48.63 a	96.18 c
HSD (5%)	2.12	2.07	2.41
Storage temperatures during shelf life			
0 °C	78.31 b	47.14	97.96
4 °C	79.04 a	47.21	98.19
HSD (5%)	0.27	NS	NS
Shelf life (month + day)			
0 + 7	79.89 a	47.45 ab	98.63
1 + 7	79.71 a	47.23 ab	98.57
2 + 7	78.14 b	46.39 b	98.11
3 + 7	78.43 b	46.57 b	98.37
4 + 7	78.10 b	47.33 a	97.72
5 + 7	77.76 b	48.08 a	97.07
HSD (5%)	0.70	1.48	NS

Different letters within columns indicate significant differences by Tukey's HSD test at $p < 0.05$. NS: nonsignificant.

in the fruit skin C^* value in hawthorn depending on the storage conditions.

The effects of storage temperatures on fruit skin h^o value were not significant (Table 3). During the cold storage period, the average fruit skin h^o value decreased from 99.58 at the beginning, to 96.18 at the end of the cold storage period of 5 months. The effects of storage and shelf-life periods on fruit skin h^o value were not significant. The changes in h^o values indicate overripening and senescence of hawthorns that are subjected to prolonged storage. These results were in agreement with those of Zandi et al. (2020) who reported a decrease in the fruit skin h^o values during the storage period in hawthorn fruit. Gallego et al. (2003) showed that fruit color changes during ripening of arazá fruit are characterized by decreased fruit skin color h^o value (increased a^* values) and increased C^* values and lightness. The decrease in h^o values indicates the change of fruit color from green to yellow, explained by chlorophyll deterioration in the fruit skin (Tuna Gunes et al., 2006). Indeed, before maturation, chlorophyll is constantly renewed. Once ripening begins, the rate of chlorophyll production slows down and the fruit begins to lose its

initial green color. As the chlorophyll decreases, a yellow coloration occurs (Cárdenas-Pérez et al., 2017).

While the average fruit flesh firmness of hawthorn fruit was determined as 20.70 N in fruit stored at 4 °C, this value was 23.66 N in those stored at 0 °C (Table 4). Firmness of hawthorn fruit at harvest time was measured as 30.24 N. This value decreased to 17.30 N throughout the cold storage period of 5 months. Average flesh firmness decreased from 23.83 N to 15.89 N during the 7-day shelf-life period after cold storage. Mean flesh firmness did not vary between 0 and 4 °C storage temperatures during shelf-life. These results were similar to those reported by Yu et al. (2006), who indicated that fruit firmness decreased during storage in hawthorn fruit kept in the refrigerator at 4 °C and normal ambient temperature. Similarly, Zandi et al. (2020) reported that the flesh firmness of hawthorn fruit at harvest time was 17.20 N, then decreased during 20 days under room (10.90 N), refrigerator (14.10 N), and cold storage (14.60 N) conditions. Fruit softening is associated with swelling of the cell walls and depolymerization of polysaccharides (Redgwell et al., 1997), and the softening mostly depends

Table 4. The effect of different storage temperatures, cold storage, and shelf-life periods on firmness, TSS, titratable acidity, and pH of Sultan hawthorn fruit.

Effects	Firmness (N)	TSS (%)	TA (malic acid %)	TSS/TA	pH
Storage temperatures during cold storage					
0 °C	23.66 a	15.26 b	1.57	9.72	3.21
4 °C	20.70 b	16.22 a	1.69	9.60	3.21
HSD (5%)	2.25	0.42	NS	NS	NS
Cold storage period (months)					
0	30.24 a	14.89 b	2.07 a	7.19 c	3.31 a
1	27.10 a	15.78 ab	1.82 ab	8.67 b	3.17 b
2	20.45 b	15.77 ab	1.69 bc	9.33 b	3.30 a
3	20.51 b	15.83 ab	1.44 cd	10.99 a	3.36 a
4	17.45 b	16.17 a	1.32 d	12.25 a	3.09 bc
5	17.30 b	15.98 ab	1.33 d	12.02 a	3.05 c
HSD (5%)	5.35	1.10	0.33	1.57	0.08
Storage temperatures during shelf life					
0 °C	22.16	16.16	1.64	9.85	3.15
4 °C	22.80	16.66	1.67	9.98	3.12
HSD (5%)	NS	NS	NS	NS	NS
Shelf life (month + day)					
0 + 7	23.83 b	16.60	1.80 ab	9.22 bc	3.18 b
1 + 7	31.02 a	16.77	1.94 a	8.64 c	3.32 a
2 + 7	23.96 b	16.86	1.93 a	8.74 c	3.31 a
3 + 7	20.22 bc	16.29	1.59 abc	10.25 bc	3.02 c
4 + 7	19.99 bc	15.79	1.42 bc	11.12 ab	3.05 c
5 + 7	15.89 c	16.15	1.26 c	12.82 a	2.95 c
HSD (5%)	6.28	NS	0.43	2.02	0.10

Different letters within columns indicate significant differences by Tukey's HSD test at $p < 0.05$. NS: nonsignificant.

on ethylene production in the fruit (Ireland et al., 2014). Therefore, various treatments such as calcium (Sen et al., 2009, Cybulska et al., 2012), 1-methylcyclopropene (1-MCP) (Özkaya and Dündar, 2009; Kurubaş and Erkan, 2018; Tomala et al., 2020), methyl jasmonate (Reyes-Díaz et al., 2016; Ozturk et al., 2019) and storage technologies such as controlled atmosphere storage and modified atmosphere packaging (Selcuk and Erkan, 2015a; Çandır et al., 2019) can be used to maintain fruit firmness during storage of hawthorn.

Hawthorn fruit stored at 4 °C had higher TSS content than those at 0 °C (16.22% and 15.26%, respectively) during storage. The TSS content of the fruit was 14.89% at the beginning of the storage period and 15.98% at the end of the 5 months. The effects of storage period and storage temperature on TSS content were not significant for the shelf-life periods in hawthorn fruit (Table 4). However, Burns (1990) suggested that hydrolysis of cell wall components may also contribute to the increase in TSS content. Similar to these findings, Zandi et al. (2020) reported that there were partial increases in the TSS content of hawthorn fruit during 20 days under room conditions, refrigerator, and cold storage. Also, Velasco-Hernández et al. (2017) stated that there was an increase in sugar content with increased respiration rate during fruit ripening of *C. mexicana*; however, the sugar content of the hawthorn fruit did not change for 8 days at 20 ± 2 °C during the shelf-life period.

Storage and shelf-life temperatures did not significantly affect average TA content (Table 4). However, the TA content of hawthorn fruit at harvest was 2.07% and it decreased to 1.33% at the end of the cold storage period. Similarly, the average of initial TA content during shelf life decreased from 1.80% to 1.26% at 5 months and 7 days. These results were consistent with the data of Zandi et al. (2020). They reported a decrease in the TA content of hawthorn fruit during the 20-day storage period under different storage conditions. Velasco-Hernández et al. (2017) showed that there was no change in the organic acid content in *C. mexicana* during the 8-day shelf life at 20 ± 2 °C. Furthermore, Ozdemir and Dundar (2006) indicated that acid loss depended on low temperature, low oxygen, and high carbon dioxide levels that slow down metabolism and respiration rate. In addition, decreases in the TA of fruit may occur as a result of the use of sugars and organic acids in respiration during storage (Selcuk and Erkan, 2015b).

The effect of storage temperature on the TSS/TA ratio and pH were not significant during cold storage and shelf-life periods in hawthorn fruit. The TSS/TA ratio increased from 7.19 to 12.02 after 5 months of cold storage. The TSS/TA ratio increased from 9.22 to 12.82 at 5 months and 7 days. Since a reduction in acidity is a factor limiting for storage, it adversely affects the TSS/TA ratio and taste

quality. However, the initial pH value of 3.31 decreased to 3.05 at the end of 5 months. The initial pH value of 3.18 decreased to 2.95 at 5 months of storage and 7 days of shelf life (Table 4). These results are similar to those reported by Arendse et al. (2014) who indicated that TSS/TA value may increase due to an increase in TSS content due to water loss and decrease in acidity content during storage of pomegranate.

According to the assessment of the panelists, prolonging the storage period decreased the appearance scores to 2.78 points at the end of 5 months (Table 5). Because this value is below 3, this is deemed unacceptable for consumers. The average appearance of fruit stored at 4 °C was lower than those stored at 0 °C (3.61 and 4.33, respectively). The effect of storage temperature on fruit appearance was significant during shelf life. While the appearance scores were above 3.00, which is an acceptable level even after 5 months in the fruit stored at 0 °C, the appearance scores fell below the acceptable level at 4 and 5 months in the fruit stored at 4 °C. The appearance scores decreased during shelf life. The initial appearance value was 4.83 and then decreased to 2.80 during the 7-day shelf-life period after 5 months of cold storage.

According to the taste scores, significant changes occurred depending on storage temperature and time. The fruit tasted at 0 °C and then checked at shelf life (8.18 and 7.63, respectively) had higher tasting scores than those stored at 4 °C (7.57 and 6.94, respectively). As storage time extended, the average of initial taste scores decreased from 8.60 to 7.00 at the end of 5 months. This value was above 5, which is acceptable to consumers. Similarly, the initial taste scores decreased from 8.37 to 6.07 after 5 months and 7 days (Table 5).

The effect of storage temperature, cold storage, and shelf-life periods on the vitamin C content of hawthorn fruit was significant (Table 6). The vitamin C content of fruit stored at 0 °C was retained for shelf life (13.46 mg 100 mL⁻¹ and 14.59 mg 100 mL⁻¹, respectively) and were higher than those stored at 4 °C (11.83 mg 100 mL⁻¹ and 12.61 mg 100 mL⁻¹, respectively). Vitamin C content was 23.27 mg 100 mL⁻¹ at the beginning of storage, but this value decreased to 11.85 mg 100 mL⁻¹ at the end of 5 months. Similarly, the vitamin C value decreased from 20.48 mg 100 mL⁻¹ to 12.00 mg 100 mL⁻¹ at the end of shelf life for 7 days after the 5 months. Razavi et al. (2018) reported a similar finding that indicated that the vitamin C content of the hawthorn *C. monogyna* fruit decreased during the storage period at 1 °C and 95% RH for 20 days. Lee and Kader (2000) reported that Vitamin C content could vary depending on the fruit species, preharvest ecology, cultural practices, the temperature during postharvest storage duration, physical injuries, chemical applications, and packaging material. In addition, losses of vitamin C

Table 5. The effect of different storage temperatures, cold storage, and shelf-life periods on sensory evaluation data of Sultan hawthorn fruit.

Effects	Appearance (1-5 point)	Taste (1-9)
Storage temperatures during cold storage		
0 °C	4.33 a	8.18 a
4 °C	3.61 b	7.57 b
HSD (5%)	0.27	0.38
Cold storage period (months)		
0	5.00 a	8.60 a
1	4.71 ab	8.40 a
2	4.03 bc	7.93 ab
3	3.99 cd	7.96 ab
4	3.32 de	7.38 b
5	2.78 e	7.00 b
HSD (5%)	0.70	0.98
Storage temperatures during shelf life		
0 °C	4.09	7.63 a
4 °C	3.51	6.94 b
HSD (5%)	NS	0.38
Shelf life (month + day)		
0 + 7	4.83 a	8.37 a
1 + 7	4.38 ab	8.21 a
2 + 7	3.97 abc	7.60 ab
3 + 7	3.65 bcd	7.01 bc
4 + 7	3.20 cd	6.46 c
5 + 7	2.80 d	6.07 c
HSD (5%)	0.95	0.98

Different letters within columns indicate significant differences by Tukey's HSD test at $p < 0.05$. NS: nonsignificant.

during the storage period are affected by storage time and atmospheric conditions in storage (Kovač et al., 2010).

The effect of storage temperature on the TAC, TP, TF, and TAn contents of hawthorn fruit was not statistically significant (Table 6). After 5 months of storage, the TAC decreased from 7.52 to 2.21 mmol TE L⁻¹, the TP from 16.86 to 16.03 mg GAE 100 mL⁻¹, and the TF from 5.53 to 3.41 mg CE 100 mL⁻¹, but there was no difference in the TAn content. While the TAC content of hawthorn fruit at 4 °C was higher than at 0 °C (5.05 and 4.36 mmol TE L⁻¹, respectively), the TP was higher at 0 °C compared to 4 °C (21.83 and 17.75 mg GAE 100 mL⁻¹). There was no statistically significant difference in the TF and TAn content during shelf life at 0 °C and 4 °C. The initial TAC decreased from 8.86 to 2.40 mmol TE L⁻¹, the TF decreased from 5.69 to 3.48 mg CE 100 mL⁻¹, and the TAn decreased from 0.24 to 0.05 mg cy-3-gluc 100 mL⁻¹ at 5 months and 7 days. On the other hand, the TP content slightly increased

from 19.12 to 20.74 mg GAE 100 mL⁻¹ at 5 months and 7 days. The data were consistent with those of Chang et al. (2006), who found that the phenolics in the hawthorn fruit were stable at 4 °C compared with 23 °C and 40 °C during storage. Similarly, Šamec and Piljac-Žegarac (2011) reported that in *C. monogyna*, fruit kept at 25 °C had higher losses for the phytochemical content (TPs, TFs, and TAn) compared to fruit stored at 4 °C. In addition, our findings were consistent with the results of studies on apple (Kovač et al., 2010), jujube (Ozturk et al., 2020), and kiwifruit (Öztürk and Yücedağ, 2021), where TPs and TFs decreased as storage time increased. On the other hand, Leja et al. (2003) showed that TPs may increase during storage due to the breakdown of tannin compounds.

The most abundant sugar is glucose in the fruit of the Sultan hawthorn cultivar (Table 7). Different storage temperatures did not affect the sugar profile of the fruit. But, the glucose, sucrose, and fructose contents of the

Table 6. The effect of different storage temperatures, cold storage, and shelf-life periods on health benefits of Sultan hawthorn fruit.

Effects	Vitamin C (mg 100 mL ⁻¹)	TAC (mmol TE L ⁻¹)	TP (mg GAE 100 mL ⁻¹)	TF (mg CE 100 mL ⁻¹)	TAn (mg cy-3-gluc 100 mL ⁻¹)
Storage temperatures during cold storage					
0 °C	13.46 a	4.85	21.83	4.20	0.13
4 °C	11.83 b	4.56	20.40	4.29	0.14
HSD (5%)	1.41	NS	NS	NS	NS
Cold storage period (months)					
0	23.27 a	7.52 b	16.86 ab	5.53 b	0.10
1	8.24 cd	9.67 a	28.09 a	6.04 a	0.17
2	7.02 d	4.77 c	14.05 b	4.74 c	0.15
3	12.17 b	1.75 d	26.46 a	2.72 e	0.13
4	13.32 b	2.33 d	25.20 ab	3.02 de	0.15
5	11.85 bc	2.21 d	16.03 ab	3.41 d	0.10
HSD (5%)	3.66	1.24	12.39	0.49	NS
Storage temperatures during shelf life					
0 °C	14.59 a	4.36 b	21.83 a	4.46	0.14
4 °C	12.61 b	5.05 a	17.75 b	4.69	0.14
HSD (5%)	0.27	0.38	1.72	NS	NS
Shelf life (month + day)					
0 + 7	20.48 a	8.86 a	19.12 ab	5.69 ab	0.24 a
1 + 7	7.92 e	7.01 b	22.79 a	6.23 a	0.13 b
2 + 7	7.68 e	5.19 c	17.24 b	5.30 b	0.14 b
3 + 7	15.64 c	2.70 d	17.74 b	3.34 c	0.11 b
4 + 7	17.87 b	2.07 d	21.12 ab	3.41 c	0.07 b
5 + 7	12.00 d	2.40 d	20.74 ab	3.48 c	0.05 b
HSD (5%)	0.68	0.98	4.48	0.81	0.09

Different letters within columns indicate significant differences by Tukey's HSD test at $p < 0.05$. NS: nonsignificant.

Table 7. The effect of different storage temperatures, cold storage, and shelf-life periods on sugar profile of Sultan hawthorn fruit.

Effects	Glucose (g 100 mL ⁻¹)	Fructose (g 100 mL ⁻¹)	Sucrose (g 100 mL ⁻¹)
Storage temperatures during cold storage			
0 °C	8.02	7.25	4.01
4 °C	8.01	7.31	3.97
HSD (5%)	NS	NS	NS
Cold storage period (months)			
0	5.86 d	6.04 d	4.62 a
1	7.22 c	6.82 c	4.34 ab
2	7.65 c	6.88 c	4.04 b
3	8.99 ab	8.12 a	3.94 bc
4	8.64 b	7.48 b	3.53 cd
5	9.74 a	8.33 a	3.47 d
HSD (5%)	0.77	0.57	0.41
Storage temperatures during shelf life			
0 °C	8.77 a	7.86 a	3.47 a
4 °C	7.58 b	6.75 b	2.96 b
HSD (5%)	0.12	0.11	0.07
Shelf life (month + day)			
0 + 7	7.55 d	7.44 a	3.76 a
1 + 7	7.97 c	7.49 a	3.06 c
2 + 7	8.20 bc	7.39 a	3.55 b
3 + 7	8.05 bc	7.05 c	3.00 c
4 + 7	8.34 b	7.10 bc	3.04 c
5 + 7	8.94 a	7.37 ab	2.91 c
HSD (5%)	0.30	0.28	0.17

Different letters within columns indicate significant differences by Tukey's HSD test at $p < 0.05$. NS: nonsignificant.

fruit in shelf life after storage at 0 °C (8.77, 7.86, and 3.47 g 100 mL⁻¹, respectively) were higher than at 4 °C (7.58, 6.75, and 2.96 g 100 mL⁻¹, respectively). During the storage period, glucose content increased from 5.86 to 9.74 g 100 mL⁻¹ and fructose content increased from 6.04 to 8.33 g 100 mL⁻¹, while sucrose content decreased from 4.62 to 3.47 g 100 mL⁻¹. The initial glucose content increased from 7.55 to 8.94 g 100 mL⁻¹ at 5 months and 7 days. The fructose content ranged between 7.49 and 7.05 g 100 mL⁻¹ at 5 months and 7 days. However, the sucrose content decreased from 3.76 to 2.91 g 100 mL⁻¹ at 5 months and 7 days. These findings were similar to those of Tuna Gunes et al. (2006), who indicated that the sucrose level in pear decreased during storage, whereas glucose and sorbitol contents increased. Similarly, Róth et al. (2007) indicated that the sucrose level in apples decreased during storage. These results are related to the invertase enzyme breaking down sucrose into glucose and fructose (Brizzolara et al., 2020). In addition, Wang et al. (2019) showed that higher sucrose content, and lower fructose and glucose contents, could be associated with reducing chilling injuries in storage duration. These results may be evidence of fluctuations in sugar content during storage in our study.

4. Conclusion

This is the first detailed study on the optimal harvest date, cold storage at different temperatures, and shelf life of the Sultan hawthorn cultivar, which is widely grown in the

Eastern Mediterranean Region of Türkiye. The results showed that the most dominant criterion in determining the harvest time of the Sultan hawthorn cultivar was the flesh firmness. The fruit of the Sultan hawthorn cultivar stored at 4 °C had higher weight losses than at 0 °C during the storage period. In addition, the fruit was extremely shriveled and the appearance scores were below the acceptable value. As a result, the fruit of the Sultan hawthorn cultivar can be stored at 4 °C and 90% RH for 3 months and at 0 °C and 90% RH for 4 months without losing any of the fruit quality and phytochemical properties. During the cold storage of this cultivar, the use of appropriate water and gas permeable modified atmosphere packaging materials can help to reduce weight loss and provide an even longer storage period. Moreover, 1-methylcyclopropan treatments and controlled atmosphere storage may be considered to protect the fruit firmness of hawthorn. Further detailed studies are needed on the postharvest physiology of this fruit species.

Acknowledgments

We would like to thank The Scientific and Technological Research Council of Türkiye (TÜBİTAK-TOVAG-118O775) for its financial support.

References

- Abdullakassim P, Songchitsomboon S, Techagumpuch M, Balee N, Swatsitang P et al. (2007). Antioxidant capacity, total phenolics and sugar content of selected Thai health beverages. *International Journal of Food Sciences and Nutrition* 58 (1): 77-85. <https://doi.org/10.1080/09637480601140946>
- Aghdam MS, Mahmoudi R, Razavi F, Rabiei V, Soleimani A (2018). Hydrogen sulfide treatment confers chilling tolerance in hawthorn fruit during cold storage by triggering endogenous H₂S accumulation, enhancing antioxidant enzymes activity and promoting phenols accumulation. *Scientia Horticulturae* 238: 264-271. <https://doi.org/10.1016/j.scienta.2018.04.063>
- Ağaoğlu YS, Çelik H, Çelik M, Fidan Y, Gülşen Y et al. (2001). Genel Bahçe Bitkileri. Yayın No: 5. Ankara, Türkiye: Ankara Üniversitesi Ziraat Fakültesi Eğitim, Araştırma ve Geliştirme Vakfı Yayınları (in Turkish).
- Alferez F, Burns JK (2004). Postharvest peel pitting at non-chilling temperatures in grapefruit is promoted by changes from low to high relative humidity during storage. *Postharvest Biology and Technology* 32 (1): 79-87. <https://doi.org/10.1016/j.postharvbio.2003.09.018>
- Arendse E, Fawole OA, Opara UL (2014). Influence of storage temperature and duration on postharvest physico-chemical and mechanical properties of pomegranate fruit and arils. *CyTA-Journal of Food* 12 (4): 389-398. <https://doi.org/10.1080/019476337.2014.900114>
- Ávila-Sosa R, Ávila-Crisóstomo E, Reyes-Arcos EA, Cid-Pérez TS, Navarro-Cruz AR et al. (2017). Effect of blue and UV-C irradiation on antioxidant compounds during storage of Hawthorn (*Crataegus mexicana*). *Scientia Horticulturae* 217: 102-106. <https://doi.org/10.1016/j.scienta.2017.01.016>
- Ayanoglu F, Caliskan O, Bayazit S, Kocer O (2023). Traditional medicinal and aromatic trees in Türkiye: Laurel (*Laurus nobilis* L.), Sumac (*Rhus coriaria* L.), Hawthorn (*Crataegus* spp.) and Carob (*Ceratonia siliqua* L.). In: Máthé Á, Turgut K (editors). *Medicinal and Aromatic Plants of Turkey*. Cham, Switzerland: Springer Nature, pp. 205-224. https://doi.org/10.1007/978-3-031-43312-2_10
- Bartolomé AP, Rupérez P, Fúster C (1995). Pineapple fruit: morphological characteristics, chemical composition and sensory analysis of Red Spanish and Smooth Cayenne cultivars. *Food Chemistry* 53 (1): 75-79. [https://doi.org/10.1016/0308-8146\(95\)95790-D](https://doi.org/10.1016/0308-8146(95)95790-D)

- Brizzolara S, Manganaris GA, Fotopoulos V, Watkins CB, Tonutti P (2020). Primary metabolism in fresh fruits during storage. *Frontiers in Plant Science* 11. <https://doi.org/10.3389/fpls.2020.00080>
- Burns JK (1990). α - and β -galactosidase activity in juice vesicles of stored Valencia oranges. *Phytochemistry* 29 (8): 2425-2429. [https://doi.org/10.1016/0031-9422\(90\)85160-H](https://doi.org/10.1016/0031-9422(90)85160-H)
- Cárdenas-Pérez S, Chanono-Pérez J, Méndez-Méndez JV, Calderón-Domínguez G, López-Santiago R et al. (2017). Evaluation of the ripening stages of apple (Golden Delicious) by means of computer vision system. *Biosystems Engineering* 159: 46-58. <https://doi.org/10.1016/j.biosystemseng.2017.04.009>
- Cemeroğlu B (2007). Gıda Analizleri. Ankara, Türkiye: Gıda Teknolojisi Yayınları, pp. 255-275 (in Turkish).
- Chang Q, Zuo Z, Chow MSS, Ho WKK (2006). Effect of storage temperature on phenolics stability in hawthorn (*Crataegus pinnatifida* var. major) fruits and a hawthorn drink. *Food Chemistry* 98 (3): 426-430. <https://doi.org/10.1016/j.foodchem.2005.06.015>
- Cybulska J, Pieczywek PM, Zdunek A (2012). The effect of Ca^{2+} and cellular structure on apple firmness and acoustic emission. *European Food Research and Technology* 235: 119-128. <https://doi.org/10.1007/s00217-012-1743-6>
- Çalışkan, O, Bayazit S, Kılıç D (2022). Alış yetiştiriciliği. In: Sülüoğlu Durul M, Polat M (editors). *Minör Meyveler I*. Ankara, Türkiye: IKSAD Publishing, pp. 3-32 (in Turkish).
- Çalışkan O, Gündüz K, Bayazit S (2018). Investigation of morphological, biological and fruit quality characteristics of Sarı Alış hawthorn genotype (*Crataegus azarolus* L.) *Journal of Agricultural Faculty of Gaziosmanpaşa University* 35: 69-74 (in Turkish with an abstract in English).
- Çandır E, Özdemir AE, Aksoy MC (2019). Effects of modified atmosphere packaging on the storage and shelf life of Hicaznar pomegranate fruits. *Turkish Journal of Agriculture and Forestry* 43 (2): 241-253. <https://doi.org/10.3906/tar-1801-119>
- Dönmez AA (2007). Taxonomic note on the genus *Crataegus* (Rosaceae) in Turkey. *Botanical Journal of the Linnean Society* 155 (2): 231-40. <https://doi.org/10.1111/j.1095-8339.2007.00682.x>
- Dursun A, Çalışkan O, Güler Z, Bayazit S, Türkmen D et al. (2021). Effect of harvest maturity on volatile compounds profiling and eating quality of hawthorn (*Crataegus azarolus* L.) fruit. *Scientia Horticulturae* 288: 110398. <https://doi.org/10.1016/j.scienta.2021.110398>
- Elyatem SM, Kader AA (1984). Post-harvest physiology and storage behaviour of pomegranate fruits. *Scientia Horticulturae* 24 (3-4): 287-298. [https://doi.org/10.1016/0304-4238\(84\)90113-4](https://doi.org/10.1016/0304-4238(84)90113-4)
- Ercisli S, Yanar M, Sengul M, Yildiz H, Topdas EF et al. (2015). Physico-chemical and biological activity of hawthorn (*Crataegus* spp. L.) fruits in Turkey. *Acta Scientiarum Polonorum. Hortorum Cultus* 14 (1): 83-93.
- Erkan M, Pekmezci M (2004). Harvest date influences superficial scald development in Granny Smith apples during long term storage. *Turkish Journal of Agriculture and Forestry* 28 (6): 397-403.
- Gallego L, Hernández MS, Fernández-Trujillo JP, Martínez O, Quicazán M (2003). Color development of arazá fruit as related to modified atmosphere packaging. *Acta Horticulturae* 628: 343-350. <https://doi.org/10.17660/ActaHortic.2003.628.41>
- Giusti MM, Wrolstad RE (2001). Characterization and measurement of anthocyanins by UV-visible spectroscopy. *Current Protocols in Food Analytical Chemistry* F1.2.1-F1.2.13. <https://doi.org/10.1002/0471142913.faf0102s00>
- Gundogdu M, Ozrenk K, Ercisli S, Kan T, Kodad O et al. (2014). Organic acids, sugars, vitamin C content and some pomological characteristics of eleven hawthorn species (*Crataegus* spp.) from Turkey. *Biological Research* 47: 21. <https://doi.org/10.1186/0717-6287-47-21>
- Gurlen A, Gundogdu M, Ozer G, Ercisli S, Duralija B (2020). Primary, secondary metabolites and molecular characterization of hawthorn (*Crataegus* spp.) genotypes. *Agronomy* 10 (11): 1731. <https://doi.org/10.3390/agronomy10111731>
- Ireland HS, Gunaseelan K, Muddumage R, Tacken EJ, Putterill J et al. (2014). Ethylene regulates apple (*Malus × domestica*) fruit softening through a dose × time-dependent mechanism and through differential sensitivities and dependencies of cell wall-modifying genes. *Plant and Cell Physiology* 55 (5): 1005-1016. <https://doi.org/10.1093/pcp/pcu034>
- Karaçalı İ (2009). Bahçe Ürünlerinin Muhafazası ve Pazarlanması. Yayın No: 494. İzmir, Türkiye: Ege Üniversitesi Ziraat Fakültesi Yayınları (in Turkish).
- Karadeniz T (2004). Şifalı Meyveler (Meyvelerle Beslenme ve Tedavi Şekilleri). Ordu, Türkiye: Burcan Ofset Matbaacılık Sanayii, pp. 34-36 (in Turkish).
- Klimczak I, Małecka M, Szlachta M, Gliszczynska-Świągło A (2007). Effect of storage on the content of polyphenols, vitamin C and the antioxidant activity of orange juices. *Journal of Food Composition and Analysis* 20 (3-4): 313-322. <https://doi.org/10.1016/j.jfca.2006.02.012>
- Kovač A, Skendrović Babojelić M, Pavičić N, Voća S, Voća N et al. (2010). Influence of harvest time and storage duration on “Cripps Pink” apple cultivar (*Malus × domestica* Borkh) quality parameters. *CyTA – Journal of Food* 8 (1): 1-6. <https://doi.org/10.1080/11358120902989632>
- Kurubaş MS, Erkan M (2018). Impacts of 1-methylcyclopropene (1-MCP) on postharvest quality of ‘Ankara’ pears during long-term storage. *Turkish Journal of Agriculture and Forestry* 42 (2): 88-96. <https://doi.org/10.3906/tar-1706-72>
- Lee SK, Kader AA (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology* 20 (3): 207-220. [https://doi.org/10.1016/S0925-5214\(00\)00133-2](https://doi.org/10.1016/S0925-5214(00)00133-2)
- Leja M, Mareczek A, Ben J (2003). Antioxidant properties of two apple cultivars during long-term storage. *Food Chemistry* 80 (3): 303-307. [https://doi.org/10.1016/S0308-8146\(02\)00263-7](https://doi.org/10.1016/S0308-8146(02)00263-7)
- McGuire RG (1992). Reporting of objective color measurement. *Hort Science* 27 (12): 1254-1255. <https://doi.org/10.21273/HORTSCI.27.12.1254>

- Ozdemir AE, Dundar Ö (2006). The effects of fungicide and hot water treatments on the internal quality parameters of Valencia oranges. *Asian Journal of Plant Science* 5 (1): 142-146.
- Ozturk A, Yildiz K, Ozturk B, Karakaya O, Gun S et al. (2019). Maintaining postharvest quality of medlar (*Mespilus germanica*) fruit using modified atmosphere packaging and methyl jasmonate. *LWT* 111: 117-124. <https://doi.org/10.1016/j.lwt.2019.05.033>
- Ozturk B, Aglar E, Gun S, Karakaya O (2020). Change of fruit quality properties of jujube fruit (*Ziziphus Jujuba*) without stalk and with stalk during cold storage. *International Journal of Fruit Science* 20 (S3): S1891-S1903. <https://doi.org/10.1080/15538362.2020.1834901>
- Özcan M, Haciseferoğulları H, Marakoğlu T, Arslan D (2005). Hawthorn (*Crataegus* spp.) fruit: some physical and chemical properties. *Journal of Food Engineering* 69 (4): 409-413. <https://doi.org/10.1016/j.jfoodeng.2004.08.032>
- Özdemir AE, Ertürk Çandır E, Kaplankıran M, Demirköser TH, Toplu C et al. (2008). Change in quality parameters during cold storage of Star Ruby grapefruits grown in Dörytol-Hatay Region. *Alatırım* 7 (2): 1-8 (in Turkish with an abstract in English).
- Özdemir AE, Yıldız E, Çandır E, Toplu C (2021). The effects of fruit development and physico-chemical changes on the optimum harvest maturity in some astringent persimmon cultivars. *Alatırım* 20 (1): 12-21.
- Özkaya O, Dündar Ö (2009). Influence of 1-methylcyclopropene (1-MCP) on 'Fuji' apple quality during long-term storage. *Journal of Food, Agriculture & Environment* 7 (2): 146-148.
- Özkaya O, Dündar Ö, Özdemir AE, Dilbaz R (2005). Effects of different postharvest applications on Red Globe grapes storage. *Alatırım* 4 (2): 44-50 (in Turkish with an abstract in English).
- Öztürk B, Yücedağ F (2021). Effects of methyl jasmonate on quality properties and phytochemical compounds of kiwifruit (*Actinidia deliciosa* cv. 'Hayward') during cold storage and shelf life. *Turkish Journal of Agriculture and Forestry* 45 (2): 154-164. <https://doi.org/10.3906/tar-2004-69>
- Payne JA, Krewer GW (1990). Mayhaw: a new fruit crop for the south. In: *Advances in New Crops. Proceedings of the First National Symposium 'New crops: Research, Development, Economics'*; Portland, USA. pp. 317-321.
- Razavi F, Mahmoudi R, Rabiei V, Aghdam MS, Soleimani A (2018). Glycine betaine treatment attenuates chilling injury and maintains nutritional quality of hawthorn fruit during storage at low temperature. *Scientia Horticulturae* 233: 188-194. <https://doi.org/10.1016/j.scienta.2018.01.053>
- Redgwell RJ, MacRae E, Hallett I, Fischer M, Perry J et al. (1997). In vivo and in vitro swelling of cell walls during fruit ripening. *Planta* 203: 162-173. <https://doi.org/10.1007/s004250050178>
- Reyes-Díaz M, Lobos T, Cardemil L, Nunes-Nesi A, Retamales J et al. (2016). Methyl jasmonate: an alternative for improving the quality and health properties of fresh fruits. *Molecules* 21 (6): 567. <https://doi.org/10.3390/molecules21060567>
- Róth E, Berna A, Beullens K, Yarramraju S, Lammertyn J et al. (2007). Postharvest quality of integrated and organically produced apple fruit. *Postharvest Biology and Technology* 45 (1): 11-19. <https://doi.org/10.1016/j.postharvbio.2007.01.006>
- Šamec D, Piljac-Žegarac J (2011). Postharvest stability of antioxidant compounds in hawthorn and cornelian cherries at room and refrigerator temperatures—comparison with blackberries, white and red grapes. *Scientia Horticulturae* 131: 15-21. <https://doi.org/10.1016/j.scienta.2011.09.021>
- SAS (2019). SAS Online Doc, Version 9.4. Cary, NC, USA: SAS Institute Inc.
- Selcuk N, Erkan M (2015a). The effects of modified and palliflex controlled atmosphere storage on postharvest quality and composition of 'İstanbul' medlar fruit. *Postharvest Biology and Technology* 99: 9-19. <https://doi.org/10.1016/j.postharvbio.2014.07.004>
- Selcuk N, Erkan M (2015b). Changes in phenolic compounds and antioxidant activity of sour-sweet pomegranates cv. 'Hicaznar' during long-term storage under modified atmosphere packaging. *Postharvest Biology and Technology* 109: 30-39. <https://doi.org/10.1016/j.postharvbio.2015.05.018>
- Sen F, Karacali I, Irget ME, Elmaci OL, Tepecik M (2009). A new strategy to enrich calcium nutrition of fruit: synergistic effects of postharvest foliar calcium and boron sprays. *Journal of Plant Nutrition* 33 (2): 175-184. <https://doi.org/10.1080/01904160903434246>
- Tomala K, Grzęda M, Guzek D, Głowska D, Gutkowska K (2020). The effects of preharvest 1-methylcyclopropene (1-MCP) treatment on the fruit quality parameters of cold-stored 'Szampion' cultivar apples. *Agriculture* 10 (3): 80. <https://doi.org/10.3390/agriculture10030080>
- Trappey AF, Johnson CE, Wilson PW (2008). Characterization of juice extraction methods utilizing fresh mayhaw (*Crataegus opaca* Hook.) fruit. *International Journal of Fruit Science* 8 (4): 318-331. <https://doi.org/10.1080/15538360802597697>
- Tuna Gunes N, Aygun A, San B (2006). Postharvest heat treatments for enhanced fruit quality during storage of early ripening European pear. *European Journal of Horticultural Science* 71 (3): 135-142.
- Velasco-Hernández A, Saucedo-Veloz C, Nieto-Ángel R, Ramírez-Guzmán ME, Saucedo-Reyes D et al. (2017). Fruit growth, maturation, and shelf life of two cultivars of tejocote (*Crataegus mexicana* Moc. & Sessé). *Fruits* 72 (2): 74-81. <https://doi.org/10.17660/th.2017/72.2.2>
- Wang L, Shan T, Xie B, Ling C, Shao S et al. (2019). Glycine betaine reduces chilling injury in peach fruit by enhancing phenolic and sugar metabolisms. *Food Chemistry* 272: 530-538. <https://doi.org/10.1016/j.foodchem.2018.08.085>
- Yilmaz KU, Yanar M, Ercisli S, Sahiner H, Taskin T et al. (2010). Genetic relationships among some hawthorn (*Crataegus* spp.) species and genotypes. *Biochemical Genetics* 48: 873-878. <https://doi.org/10.1007/s10528-010-9368-6>

- Yu W, Lite L, Jianxiong H (2006). Changes of hawthorn pectase activity and pectin content during storage. *Academic Periodical of Farm Products Processing* 15 (2): 11-12 (in China).
- Zandi M, Ganjloo A, Bimakr M (2020). Development of quality grading system based on image processing for hawthorn classification during various storage condition (cold, refrigerator, and room). *Journal of Food Researches* 30 (1): 195-209 (in Arabic with an abstract in English).
- Zhishen J, Mengcheng T, Jianming W (1999). The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. *Food Chemistry* 64 (4): 555-559. [https://doi.org/10.1016/S0308-8146\(98\)00102-2](https://doi.org/10.1016/S0308-8146(98)00102-2)