Unal S and Sabir FK (2023)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 51, Issue 1, Article number 13037
DOI:10.15835/nbha51113037
Research Article

UV-C treatments extend the postharvest quality of '0900 Ziraat' sweet cherries by protecting the physical and biochemical features of the fruits during the storage

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Abstract

Sustainable practices to extend the postharvest quality of horticultural products lead to cost-effective marketing during the prolonged season. Sweet cherries are among the most commonly consumed and traded fruits worldwide although they necessarily deteriorate after harvest. In the present study, the effects of UV-C irradiation in different application durations along with modified atmosphere packaging (MAP) on quality maintenance of the '0900 Ziraat' sweet cherries were investigated for two years (2018 and 2019). The fruits were divided into six application groups; (1) storage in plastic cups control, (2) using MAP (Xtend®) packages, (3) 5 min UV-C exposure, (4) 10 min UV-C, (5) 20 min UV-C, and (6) 30 min UV-C irradiation. Treatment of UV-C was performed at a 15 cm distance using a metal cabinet equipped with 8 UV-C lamps of 15 watts, 230V/50Hz at 254 nm wavelength. The sweet cherries were stored at 1 °C and 90% RH for 35 days. At the end of the storage, the greatest weight loss occurred in the control fruits, while the lowest loss was obtained from the fruits subjected to 10 min of UV-C for both years. Also, 10 min of UV-C provided the highest firmness value for both years. This treatment also has better effects on maintaining several quality features such as pedicel chlorophyll content, titratable acidity in fruit juice, and total phenolic contents compared to the control fruits. General findings indicated that 10 min UV-C irradiation would be a beneficial practice for extending the general quality features of '0900 Ziraat' sweet cherry during cold storage up to 35 d.

Keywords: fruit storage; fruit quality maintenance; postharvest physiology; *Prunus avium* L.

Introduction

The sweet cherry (*Prunus avium* L.) is an attractive stone fruit with high consumer demands around the world due to its high levels of essential nutrients as well as bioactive compounds such as anthocyanins, fructose, flavonols, glucose, quercetin, and vitamins (Wani *et al*., 2014). Accordingly, sweet cherry production and trade are very extensive globally. The annual world production of sweet cherry was approximately 2.5 million tons and the leading producers in the world were Türkiye, the United States of America, Chile, Uzbekistan, and Iran (Faostat, 2021). However, the fruits are highly perishable due to their susceptible texture to physiological disorders such as pitting, and fungal rots that limit the shelf life of fruits (Alique *et al.*, 2005).

Received: 11 Dec 2022. Received in revised form: 30 Jan 2023. Accepted: 08 Feb 2023. Published online: 16 Feb 2023.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

In recent years, '0900 Ziraat' sweet cherry cultivar has attracted great attention in Türkiye due to its large, sweet, hard, and crack-resistant fruits with attractive unique dark color. As seen in many other sweet cherry cultivars, '0900 Ziraat' fruits necessarily lose their quality after harvest due to easily perishable fruit nature that shows softening and loss of color, browning of the fruit stem color, and rotting.

To control physiological disorders and pathological diseases that cause a quality loss in sweet cherries after harvest, certain physical and chemical treatments such as controlled and modified atmosphere packaging, storage at hypobaric pressure, pre-cooling, hot treatments, radio frequency, and microwave treatments, and ultraviolet light (UV) exposure have been employed by various researchers (Turtoi, 2013; Usall *et al*., 2016). UV-C light treatment is a methodology approved by the United States Food and Drug Administration (FDA) for postharvest use in fresh fruits and vegetables, and is used to control microorganisms on products and to induce resistance to pathogens, delay ripening and improve postharvest storage life (Şen and Karaçalı, 2005; Pinheiro *et al*., 2015). When microorganisms on the surface of fruits and vegetables are exposed to UV light, the DNA of pathogens is degraded, causing their death by damaging the reproliferating structures in the cells. At the same time, UV exposure induces the biosynthesis of phytoalexin compounds, which protect the products against subsequent infections (Urban *et al*., 2016). With UV-C treatment, the activity of enzymes that are effective in the defense mechanism of produces also increases, and in this way bacterial growth is inhibited (Gil *et al*., 2009; Xu *et al*., 2016). In this study, the effects of UV-C light treatments at different times on fruit quality in '0900 Ziraat' cherry variety were investigated under cold storage and conditions.

Materials and Methods

Study design

In the study, the fruits of the '0900 Ziraat' sweet cherry cultivar were harvested from a commercial orchard in Aksehir (Konya) at commercial maturity. The fruits were immediately transferred to the postharvest laboratory of Selcuk University, Agriculture Faculty in a cooled vehicle. In the laboratory, the fruits were selected to ensure uniformity in terms of size and color, and divided into 6 equal parts for postharvest treatments as follows; (1) storage in plastic cups without treatment as control, (2) placing the cherry cups in Xtend® modified atmosphere packages (MAP), (3) UV-C light exposure for 5 min, (4) UV-C light exposure for 10 min, (5) UV-C light exposure for 20 min, and (6) UV-C light exposure for 30 min. For UV-C treatment a metal cabinet equipped with 8 UV-C lamps of 15 watts, 230V/50Hz were used at 254 nm wavelength. For UV-C treatment, the sweet cherries were placed on a shelf at an equal (15 cm) distance from the UV-C lamps. Treatment doses were checked using IL1700 model radiometer (International Light, Inc., Newburyport, MA. 01950) and were 1.8 kJ/m^2, 3.6 kJ/m^2, 7.2 kJ/m^2 and 10.8 kJ/m^2 for 5-, 10-, 20- and 30-min exposure were respectively. A total of 15 plastic rigid cups containing 500±20 g fruits were used for each treatment. The sweet cherry cups after treatments were stored in a cold storage room at 1 °C and 90% relative humidity condition for 35 days. Certain physical and biochemical quality analyzes were carried out by sampling the cherry fruits from the store at 7-day intervals.

Physical and biochemical investigations

The weight loss was calculated by weighing the cherry fruits with a precision scale. The fruit firmness was determined with a digital penetrometer from two mutual points of each fruit using an 8 mm tip, and the results were determined as Newton (N). Skin color (Hue angle) of the fruits was recorded with a chronometer device (Minolta CR 400) (McGuire, 1992). For visual quality evaluation, a scale of 1-9 in terms of external appearance, firmness, and color of fruits was assessed by the panelists as poor- not edible (1), medium-consumable limit, material defects do not affect the marketability of the product (3), good, marketable limit, small defects do not affect the marketability of the product (5), very good in general condition (7), excellent, as fresh as newly harvested (9) (Hayta and Aday, 2015). In each analysis period, decayed fruits were counted on

the existence of defects on the skin and the results were expressed as % by proportioning to the total number of fruits. Titratable acidity (TA), was determined as % malic acid by titrating the fruit juice with 0.1 N NaOH until the endpoint of the pH 8.1. The total amount of chlorophyll in the stems of stored cherries was obtained with the spectrophotometric method. For this aim, the ground cherry stalks were extracted using a mixture of chloroform:methanol (2:1). After filtering the solution, the absorbance value was read at 663 and 645 nm wavelengths in the spectrophotometer using the chloroform:methanol standard. The total amount of chlorophyll was calculated with the Mc Kinney equation and the results were given as mg/100g (Küçükbasmacı *et al*., 2008).

For total phenol and total antioxidant analyses, the fruit samples were mashed with a blender and homogenized with 25 ml of methanol. The preparate was kept at 4 °C for 16 hours and then centrifuged (Thaipong *et al*., 2006).

Total phenolic content (TPC) was determined by the spectrophotometric method using the Folin-Ciocalteu reagent. 100 µL of the extracted sample was diluted with adding distilled water and the obtained solution was taken into the flask. After adding the Folin-Ciocalteu reagent, the mixture was shaken and left at room temperature for 3 min. Then, a saturated sodium carbonate solution was added and the flask was filled with distilled water. After incubation for 2 hours at 25 °C, the solution was read at 760 nm wavelength in the spectrophotometer and the results were given as mg/100g (Singleton *et al*., 1999). Antioxidant activity (AA) was obtained with Ferric Reducing Antioxidant Power (FRAP). 2850 µL of FRAP was added to 150 µL of sample extract and the solution was kept in the dark for 30 min. At the end of this period, readings were performed in the spectrophotometer at a wavelength of 593 nm. FRAP antioxidant activity was expressed as µmol/g/fresh weight by calculating the values obtained with the standard curve of trolox (6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid) prepared at 10-100 µmol/l concentrations (Benzie and Strain, 1996). The pH differential method was used to determine the total monomeric anthocyanin (TMA). Dilution was made by placing 1.9 ml of pH 1.0 (potassium chloride) and pH 4.5 (sodium acetate) solutions on 0.1 ml of fruit extract. In the solutions obtained, absorbance values were read against pure water at 520 nm and 700 nm after 20 min. The results were evaluated according to cyanidin-3-rutinoside (mg/100 g) (Cheng and Breen, 1991). Polygalacturonase (PG) enzyme activity Miller (1959), Pathak and Sanwal (1998) was determined by performing slight modifications to the DNS method. For PG analysis, 100 µl of pectin solution was added to 20 µl of sample and the solution was incubated in an oven at 30 °C for 10 min. The incubated solution was supplemented with 120 µl and kept in a water bath at 96 °C for 4 min. It was then cooled in ice for 3 min. spectrophotometer Reading was performed at a wavelength of 530 nm.

Statistical analyses

The study was conducted with the randomized plot design with 3 replications of 500 g fruit sample per replication. The data were subjected to analysis of variance using the JMP package program, and the differences between the means were evaluated according to Student's t-test multiple comparison test ($p<0.05$).

Results and Discussion

Effects of postharvest MAP and UV-C treatments on the weight loss, firmness, skin color, visual quality, and total chlorophyll content of '0900 Ziraat' sweet cherry fruits were presented in Table 1 (2018) and Table 2 (2019).

Weight loss

Treatments significantly delayed the weight loss of the fruit during the 35-d storage for both years. The fruit weight gradually decreased with the storage time with the highest increases in control fruits for all analyses dates of the years. In 2018, the greatest loss in fruit weight occurred in the control group fruits (22.42%) while

the lowest weight loss was obtained from the fruits subjected to 10 min of UV-C (0.99%) which was followed by 5 min of UV-C (1.04%) and MAP (1.10%). In 2019, the highest weight loss was determined in the control fruits (10.83%), followed by 20 min UV-C (1.58%), while the least weight loss occurred in fruits subjected to 10 min UV-C (0.82%) followed by MAP C (0.94%), 5 min UV-C (0.93%). Physiologically, postharvest exposure of fresh fruits to UV-C radiation remarkably delays water loss by preventing the structure of the cell membrane of the commodities, limiting respiration rate and transpiration (Abdipour *et al*., 2020). Findings of the present and the previous studies revealed that UV-C alone or in combination with many other treatments were capable of delaying the loss in fruit weight. For example, Koçak and Bal (2017) reported that the lowest weight loss was obtained from UV-C plus MAP treatment in '0900 Ziraat' sweet cherry. Similarly, UV-C plus hot water in 'Starks Gold' Durmaz (2019) and UV-C plus chitosan treatments in 'Takdaneh Mashhad' Abdipour *et al*. (2020) significantly retarded the weight loss of the sweet cherries.

Firmness

In 2018, the firmness of the fruits initially was 8.88 N and underwent gradual decreases along with the progressive storage duration. A remarkable decrease was detected after the 14th storage day in the firmness of the fruits although the treatments did not significantly affect this feature during the 35-d storage. At the end of the storage, the greatest and the lowest firmness values were determined in 20 min UV-C (6.20 N) and control fruits (3.94 N), respectively. In 2019, postharvest treatments had significantly positive effects on maintaining the firmness of the fruits from the beginning of the storage till the end. At the end of the storage, the greatest firmness values were obtained from 10- and 5-min UV-C treatments (4.64 and 4.52 N, respectively) in the same statistical group. Exposure of the fruits to 10 min UV-C provided 17 and 41% higher firmness values than control fruits at the end of the storage duration of the 2018 and 2019 years, respectively.

Firmness is a quality parameter that determines the success of the postharvest storage of perishable products like sweet cherries. The softening that increases with the senescence of horticultural products occurs due to the activity of enzymes such as pectin methyl esterase (PME), polygalacturonase (PG), and methyl esterase (ME). These enzymes destroy pectin substances in the fruit cells, causing loss of firmness (Barreit and Gonzalez, 1994; Atkinson *et al*., 2012). Treatments that slow down the activity of these enzymes are effective in delaying softening. The decrease in firmness of the fruit is closely related to weight loss and metabolic changes that occur due to water loss during storage (García *et al*., 1998). Indeed, Abdipour *et al*. (2020) stated that UV-C treatment inhibits ethylene synthesis, reduces respiration rate, and as a result slows down the activities of enzymes that cause softening. Firmness findings indicated that UV-C treatments probably slowed down the metabolic activity of the sweet cherry fruits, with the highest effect of 10 min exposure to UV-C treatment. Similar effects of postharvest UV-C treatment were also reported for certain perishable fruits such as strawberry Sabir *et al*. (2018), plum Bal and Çelik (2008), peach Gonzalez-Aguilar *et al*. (2004) and mango Promyou and Supapvanich (2016) fruit species It has been stated that is effective in maintaining the firmness.

Skin color

In the first year, the Hue angle value of the sweet cherries was not significantly affected by the treatments although it displayed a general decrease with slight fluctuations during the storage. Nonetheless, the greatest decrease in Hue angle occurred in nontreated control fruits from 21.00° at day 0 to 15.05° at the end of 35 d storage while the lowest change was determined in 10 min UV-C treatment (17.53°). In the second year, the treatments significantly delayed the decrease in Hue angle, except for the highest UV-C dose (30 min UV-C), according to the final observations on 35th d. Similar to the first year, 10 min UV-C treatment with the greatest value (18.95°) was the most effective one to delay loss in Hue angle in the second year. Higher doses of UV-C were not efficient enough protective on maintaining the Hue angle of the sweet cherries. Studying the cold storage of the strawberry, Sabir *et al*. (2018) also reported better effects of 15 min of UV-C treatment in

protecting color properties compared to control and 30 min of UV-C treatment, although Pan *et al*. (2004) did not find significant differences in Hue angle value of the strawberry fruits in response to UV-C treatment.

Visual quality

The visual quality of the sweet cherries underwent a gradual but treatment-dependent decrease along with the prolonged cold storage duration for both two years. At the end of the storage duration, all the treatments were significantly effective to maintain the visual quality of the fruits with the greatest effects of UV-C treatments of 10- and 20-min exposure with the same score (5.11) for the first year and 5 min for the second year with a high panelist score (7.00). On the other hand, the control fruits received the lowest scores, 2.00 and 3.00 for the first and second years, respectively. The fruits belonging to control and 30 min UV-C exposure in the first year and only control fruits in the second year were below the marketability threshold (5.00).

Maintaining the postharvest visual quality of fresh perishable fruits is a prime consideration affecting storage success as one of the major determinants of consumer preference (Abdipour *et al*., 2020). MAP and UV-C treatments, except for 30 min exposure which caused darkening in the pedicel of the fruits, were capable of maintaining the visual quality of the sweet cherries at a marketable level during the 35-d storage. Studying peach fruits, one of the most perishable horticultural produces, On the other hand, Gonzalez-Aguilar *et al*. (2004) concluded that UV-C exposure in 15 and 20 min caused the darkening of the fruit skin in peaches. The postharvest visual quality of the plum fruits of the 'Giant' cultivar was also improved by 10 min UV-C treatment (Bal and Çelik, 2008). The findings of the present and the previous studies indicated the differential responses of fruit species to UV-C exposure duration (Sabir *et al*., 2020; Abdipour *et al*., 2020).

Total Chlorophyll Content (TCC)

TTC content of the fruit pedicel displayed a sharp decrease from the beginning of the storage till the end. The greatest decreases were generally determined in control fruits, while the lowest changes occurred in the fruits 5- and 10-min UV-C treatments for both two years at the end of the storage. In the first year, the greatest TTC was found in the 10 min UV-C treatment (11.77 mg/100g), after a lower change course during the storage. Control fruits suffered from the greatest loss in TTC with a remarkable decrease from 17.34 to 5.84 mg/100g. In the second year, the lowest TCC was determined in the control group fruits due to darkening and drying on the fruit stalks (7.36 mg/100g), while the highest value was determined in 20- and 10-min UV-C with similar effects (10.91 and 10.61 mg/100g, respectively) at the end of the storage.

Desiccation of sweet cherry fruit pedicel is one of the most important quality changes that occur after harvest and causes a decrease in the market value. The pedicel of the sweet cherry is more susceptible to water loss than the fruit as it has a thinner cuticle and epidermis (Chockchaisawasdee *et al*., 2016). In the present study, chlorophyll degradation in pedicel was higher than in nontreated control fruits, and 30 min exposure to UV-C was possible due to high water loss, while 10 min UV-C treatment remarkably delayed chlorophyll degradation during cold storage for both years. Other postharvest treatments such as high ambient humidity Kupferman and Sanderson (2005), Küçükbasmacı *et al*. (2008), edible film coatings with sodium bicarbonate, thujen and carvacrol Göksel (2011) besides chitosan and *Aloe vera* Çınar and Sabır (2021) were also reported to be effective in protecting the green color of the pedicel of the sweet cherry.

Table 1. Effects of UV-C treatments on the weight loss, firmness, skin color, visual quality, and total chlorophyll content (TCC) of '0900 Ziraat' sweet cherry fruits during cold storage (first year)

	Weight loss (%)	Firmness (N)	Skin color (Hue angle)	Visual quality	TCC (mg/100g)
Day 0	0.00 i	8.88	21.00	9.00 a	17.34 a
Day 7					
Control	4.98 e	7.36	16.95	7.38 def	12.05 b-f
MAP	0.51 hi	7.40	18.51	8.43 ab	13.34 b
5 min UV-C	0.62 ghi	8.69	16.51	7.48 def	12.97 bc
10 min UV-C	0.64 ghi	8.18	17.33	8.81 a	13.00 bc
20 min UV-C	0.62 ghi	8.61	18.08	8.62 ab	12.70 bcd
30 min UV-C	0.61 ghi	8.05	20.19	7.67 cde	12.61 b-e
Day 14					
Control	9.30 d	6.61	14.87	5.27 kl	8.99 kl
MAP	0.62 ghi	6.93	16.30	8.33 abc	10.90 e-j
5 min UV-C	0.62 ghi	7.66	16.76	7.13 efg	12.82 bcd
10 min UV-C	0.63 ghi	7.57	15.95	8.47 ab	11.10 d-i
20 min UV-C	0.79 gh	7.44	17.13	8.07 bcd	11.48 c-h
30 min UV-C	0.81 gh	7.39	16.52	7.00 e-h	11.12 d-i
Day 21					
Control	9.30 d	6.12	16.29	3.86 mn	7.52 lm
MAP	0.62 ghi	7.77	16.46	6.81 fgh	9.59 ıjk
5 min UV-C	0.62 ghi	7.02	15.48	5.57 k	11.39 c-h
10 min UV-C	0.63 ghi	7.38	18.65	6.33 hıj	11.56 c-g
20 min UV-C	0.79 gh	7.16	17.21	6.43 ghı	9.22 jkl
30 min UV-C	0.81 gh	7.25	18.17	5.38 k	10.31 g-k
Day 28					
Control	16.64 b	5.23	14.71	3.29 n	5.17 n
MAP	0.90 fgh	5.49	15.60	5.67 jk	10.27 g-k
5 min UV-C	0.99 fgh	6.16	16.14	5.67 jk	11.34 c-h
10 min UV-C	0.86 fgh	7.02	16.74	5.77 ıjk	9.78 h-k
20 min UV-C	1.07 fgh	6.36	16.91	5.10 kl	10.64 f-k
30 min UV-C	0.94 fgh	6.73	17.47	5.38 k	10.30 g-k
Day 35					
Control	22.42 a	3.94	15.05	2.00 o	5.84 mn
MAP	1.10 fgh	5.02	15.22	4.56 lm	9.15 kl
5 min UV-C	1.04 fgh	5.00	16.67	4.56 lm	10.49 f-k
10 min UV-C	0.99 fgh	6.68	17.53	5.11 kl	11.77 b-g
20 min UV-C	1.26 fg	6.20	16.56	5.11 kl	9.77 h- k
30 min UV-C	1.29 fg	5.18	16.72	3.22 n	6.91 m
$LSD_{0.05}$	0.70	N.S.	N.S.	0.74	1.73

Each value represents the mean of three replicates. The values within a column with different letters are significantly different at $P \leq 0.05$ according to the Student's t-test. N.S.: Non-significant.

Table 2. Effects of UV-C treatments on the weight loss, firmness, skin color, visual quality, and total chlorophyll content (TCC) of '0900 Ziraat' sweet cherry fruits during cold storage (second year)

	Weight loss (%)	Firmness (N)	Skin color (Hue angle)	Visual quality	TCC (mg/100g)
Day 0	0.00 i	8.11 a	20.85 c-h	9.00 a	15.15
Day 7					
Control	3.63 d	7.04 cd	20.09 e-i	9.00 a	11.99
MAP	0.31 hi	7.53 bc	21.48 b-e	9.00 a	15.03
5 min UV-C	0.39 hi	8.08 a	20.44 d-i	9.00 a	12.47
10 min UV-C	0.43 hi	7.43 c	20.90 c-g	9.00 a	14.25
20 min UV-C	0.42 hi	7.99 ab	21.34 b-e	9.00 a	14.51
30 min UV-C	0.36 hi	6.65 de	22.72 bc	9.00 a	13.48
Day 14					
Control	4.24 d	6.30 ef	18.94 i-l	8.67 a	11.24
MAP	0.41 hi	5.85 fg	21.62 b-e	9.00 a	14.14
5 min UV-C	0.47 hi	6.44 e	22.29 bcd	8.89 a	12.03
10 min UV-C	0.45 hi	6.62 de	21.26 b-f	8.89 a	12.01
20 min UV-C	0.74 f-i	6.47 e	20.01 e-i	8.89 a	10.63
30 min UV-C	0.79 e-h	5.89 f	25.19 a	8.89 a	10.78
Day 21					
Control	5.38 c	4.46 jkl	18.74 i-l	5.44 gh	10.67
MAP	0.50 ghi	4.74 i-l	19.88 e-i	8.78 a	10.86
5 min UV-C	0.51 ghi	5.19 hi	20.38 e-i	7.00 b	11.32
10 min UV-C	0.49 hi	5.35 gh	19.42 f-j	6.56 bcd	11.67
20 min UV-C	1.10 e-h	4.84 ij	20.36 e-i	6.00 ef	12.08
30 min UV-C	0.98 e-h	4.77 ijk	23.07 b	5.67 fg	11.75
Day 28					
Control	6.90 b	4.28 klm	17.23 k-n	5.11 h	10.14
MAP	0.54 ghi	4.48 jkl	17.05 lmn	6.44 cde	11.44
5 min UV-C	0.73 ghi	4.76 ijk	18.67 i-l	6.89 bc	11.65
10 min UV-C	0.61 ghi	4.74 i-l	18.67 i-l	6.22 de	11.99
20 min UV-C	1.29 efg	4.59 jkl	19.09 g-k	5.67 fg	12.61
30 min UV-C	1.04 e-h	4.28 klm	19.20 g-j	5.56 fgh	11.29
Day 35					
Control	10.83 a	3.86 m	15.98 n	3.00 i	7.36
MAP	0.94 e-h	4.36 j-m	17.55 j-n	6.89 bc	9.99
5 min UV-C	0.93 e-h	4.52 jkl	16.22 mn	7.00 b	10.07
10 min UV-C	0.82 e-h	4.64 jkl	18.95 h-l	6.00 ef	10.61
20 min UV-C	1.58 e	4.33 j-m	17.92 j-m	6.78 bc	10.91
30 min UV-C	1.53ef	4.24 lm	15.95 n	5.33 gh	9.65
$LSD_{0.05}$	0.79	0.51	1.90	0.55	N.S.

Each value represents the mean of three replicates. The values within a column with different letters are significantly different at $P \leq 0.05$ according to the Student's t-test. N.S.: Non-significant.

Effects of postharvest MAP and UV-C treatments on titratable acidity (TA), total phenolic content (TPC), total antioxidant capacity (TAC), total monomeric anthocyanin (TMC), and polygalacturonase activity (PG) of '0900 Ziraat' sweet cherry fruits were presented in Table 3 (2018) and Table 4 (2019).

Titratable acidity (TA)

As expected, TA values of the fruit juice decreased with the progression of the storage period in cold-stored fruits for both years, although postharvest treatment did not significantly affected the TA for the first year. However, treatment significantly retarded the loss of TA during storage. In the second year, the highest TA value was measured in the fruits treated with 10 min of UV-C (0.360%). This treatment was followed by 20 min of UV-C (0.351%), 30 min of UV-C (0.344%), MAP, and 5 min of UV-C (0.340%) treatments, respectively. The lowest TA value was determined in the control fruits (0.324%). Organic acids, particularly malic and citric, have essential contributions to the biochemical features of horticultural crops in varying proportions (Vallarino and Osorio, 2019). TA change mainly resulting in respiration in crops after harvest, depends on many factors (Rivera-Pastrana *et al*., 2007). In the present study, the decrease in TA with the progression of storage time was generally delayed with MAP or UV-C, particularly in the second year with the greatest effect of 10 min UV-C. Similar effects of UV-C were also reported by Bal and Çelik (2008) in plum, Koçak and Bal (2017) and Abdipour *et al*. (2020) in sweet cherries, Xu and Liu (2017) in blueberry, Sabir *et al*. (2018) in strawberry.

Total phenolic content (TPC)

TPC of the sweet cherry fruits underwent a general decrease for both years, although there was a slight decrease for the first week of the first year. Treatments were generally effective in delaying the changes in TPC during storage. The greatest increase in TPC was observed in the fruits exposed to 30 min of UV-C (109.60 mg/100g), followed by control (104.05 mg/100g). The TPC values of the MAP (83.77 mg/100g) and 10 min UV-C (89.32 mg/100g) treatments were very close to that of the initial value (85.34 mg/100g). In the second year, the initial TPC was 42.74 mg/100g and tended to increase with treatment-dependent changes during the storage. At the end of the 35-d storage, the TPC changed between 80.89 mg/100g (5 min UV-C) and 116.63 mg/100g (control) values with the greatest effect of 5 min UV-C on delaying the TPC increase. Phenolic compounds, as secondary metabolites with various protective properties in plants, affect the biochemical quality of fruits as these compounds directly affect the fruit color, taste, and aroma (Chockchaisawasdee *et al*., 2016; Valero, 2017). Physiologically, the polyphenol oxidase (PPO) enzyme, which causes darkening in products, occurs with the increase of phenolic substances (Lu *et al*., 2011). Therefore, delaying the increase in TPC is one of the major aims in the cold storage of commodities. The synthesis of phenolic substances is regulated by various stress conditions and environmental factors, and the TPC amount varies according to the genotype, growth conditions, maturity stage as well as harvest and storage conditions. UV-C treatments are used to regulate the TPC in fruits and vegetables. A similar positive effect of 15 min UV-C irradiation was also reported by Sabir *et al*. (2018) who studied postharvest cold storage of the 'Albion' and 'Monterey' strawberry fruits. Abdipour *et al*. (2020) stated that 21.6 kj/m^2 UV-C treatment was effective in protecting the amount of phenolics in sweet cherries. Contrary to our findings, Zhang *et al*. (2021) stated that 1.05, 2.10, and 4.20 kJ/m^2 UV-C caused increases in the TPC of sweet cherry fruits during storage. Studies indicated that appropriate use of UV-C treatments slows down the changes in the amount of phenolic substances by restricting the activity of phenylalanine aminoliase (PAL) which causes senescence.

Total Antioxidant Capacity (TAC)

In the first year, TAC value of the sweet cherry fruits was not significantly affected by postharvest treatments although it slightly tended to decrease during the storage. In the second year, the TAC underwent a progressive decrease up to the 28th d and then displayed a slight increase until the 35th d of storage with treatment-dependent changes. At the end of the storage, the greatest TAC was measured in the control fruits (114.85 µmol/g), followed by 20 min UV-C (108.04 µmol/g) and MAP (107.47 µmol/g). The lowest TAC value was determined in fruits treated with UV-C for 5 min (90.93 µmol/g) and 10 min UV-C (100.02 µmol/g) which showed a closer value to that of the initial analysis (96.10 µmol/g). The antioxidant potential of fruits is

closely related to their polyphenolic compounds, phenolic substances, and ascorbic acid content (Chaovanalikit and Wrolstad, 2004). It is emphasized that preharvest and postharvest treatments directly affect the nutritional content and biochemical features of fresh fruits and vegetables. Studying on postharvest quality response of strawberries to UV-C irradiation, Erkan *et al*. (2008) and Sabr *et al*. (2018) emphasized that a higher rate of antioxidant activity was detected in fruits treated with UV-C compared to the control during cold storage.

Total Monomeric Anthocyanin (TMA)

In the first year, TMC displayed a general decreasing trend although there were certain unstable increases during the storage. At the end of the 35-d storage, the highest TMC was measured in 10 min UV-C treatment (18.19 mg/100g), followed by MAP (15.57 mg/100g), while the lowest value was determined in the control group (11.16 mg/100g). Exposure of the fruits to 10 min UV-C (18.19 mg/100g) resulted in the nearest TMC value to that of the initial value (20.67 mg/100g). TMC, which was 24.94 mg/100g at the beginning of storage in the second experimental year, changed between 21.08 mg/100g (20 min UV-C) and 34.03 mg/100g (MAP) values on the 35th day of storage with the progress of storage. TMC, MAP and 10 min UV-C treatments were statistically in the same group. Changes in TMC of the sweet cherry fruits were quite different from the first year. There was a remarkable decrease during the first week of the storage in the second year, however gradual and treatment-dependent increases were detected in TMC after the first week. At the end of the storage, the TMC ranged from 21.08 mg/100g (20 min UV-C) to 34.03 mg/100g (MAP) with the nearest value obtained from 30 min UV-C (22.32 mg/100g) treatment to that of the initial value (24.94 mg/100g).

Anthocyanins are water-soluble vacuolar pigments that give the products red, purple, or blue color depending on the pH of the environment. During ripening, the amount of anthocyanins increases with the increase in the sugars in their structure, but due to the decomposition of the sugars in their structure with excessive ripening and senescence, the fruit color darkens as a result of oxidative reactions, which results in a decrease in the hue value of the fruits (Jaakola, 2013). In the study, a higher TMC was detected in fruits treated with UV-C for 10 min during cold storage. Severo *et al*. (2017) stated that UV-C treatment increases anthocyanin biosynthesis in fruit peel by 44%. Zhang *et al*. (2021) stated that higher TMC was determined in UV-C light treatments in cherries stored at room temperature. In studies conducted on strawberries, cherries, and blueberries, it was stated that UV-C treatments increased TMC (Kataoka *et al*., 1996; Baka *et al*., 1999; Xu and Liu, 2017).

Polygalacturonase activity (PG)

PG enzyme activity of the sweet cherries was almost constant during the cold storage for both years. Therefore, neither of the treatments affected the changes in PG enzyme activity. Nonetheless, the greatest change in PG at the end of the storages for both years was detected in control fruits, while on the other hand, the lowest changes were determined in the fruits subjected to 10 min UV-C.

Table 3. Effects of UV-C treatments on the titratable acidity (TA), total phenolic contents (TPC), total antioxidant capacity (TAC), total monomeric anthocyanin (TMA), and polygalacturonase activity (PG) of '0900 Ziraat' sweet cherry fruits during cold storage (first year)

	TA (%)	TPC (mg/100g)	TAC (µmol/g)	TMA (mg/100g)	PG (mmol/kg/h)
Day 0	0.804	85.34 c-g	73.71	20.67 ab	0.97
Day 7					
Control	0.664	73.77 e-k	77.06	15.29 gh	0.97
MAP	0.697	70.81 g-k	52.44	18.74 bcd	0.92
5 min UV-C	0.631	63.40 jk	54.78	22.46 a	0.98
10 min UV-C	0.723	69.69 h-k	46.34	18.32 bcd	0.93
20 min UV-C	0.689	72.29 f-k	49.02	14.88 ghi	0.96
30 min UV-C	0.637	65.34 ijk	52.10	15.29 gh	0.80
Day 14					
Control	0.607	89.32 bcd	68.24	12.81 i-l	1.00
MAP	0.541	60.43 k	46.90	11.30 lm	0.86
5 min UV-C	0.576	78.68 d-j	67.15	17.91 c-f	0.95
10 min UV-C	0.520	66.08 ijk	55.91	17.22 c-g	0.85
20 min UV-C	0.550	74.79 d-k	46.54	12.81 i-l	0.88
30 min UV-C	0.541	68.12 ijk	64.38	11.57 klm	0.96
Day 21					
Control	0.578	95.81 abc	60.30	15.71 e-h	0.97
MAP	0.573	86.55 c-f	57.19	12.40 j-m	0.86
5 min UV-C	0.580	85.90 c-g	55.93	19.15 bc	0.97
10 min UV-C	0.576	65.71 ijk	46.58	18.05 cde	0.91
20 min UV-C	0.609	72.75 e-k	50.64	10.20 m	0.85
30 min UV-C	0.589	78.58 d-j	59.17	13.78 h-k	0.98
Day 28					
Control	0.501	95.81 abc	59.59	14.19 hij	1.04
MAP	0.503	87.75 cde	57.97	16.67 d-g	0.99
5 min UV-C	0.487	74.88 d-k	55.00	13.92 h-k	0.96
10 min UV-C	0.536	72.01 f-k	51.61	14.05 hij	0.99
20 min UV-C	0.497	78.21 d-j	40.40	10.33 m	0.95
30 min UV-C	0.479	78.86 d-i	45.53	13.92 h-k	1.00
Day 35					
Control	0.443	104.05 ab	69.97	11.16 lm	1.07
MAP	0.478	83.77 c-h	66.88	15.57 fgh	1.01
5 min UV-C	0.480	78.68 d-j	67.57	14.88 ghi	1.01
10 min UV-C	0.491	89.32 bcd	61.17	18.19 cd	0.95
20 min UV-C	0.478	94.97 abc	54.68	12.81 i-l	1.01
30 min UV-C	0.443	109.60 a	61.77	11.57 klm	1.04
$LSD_{0.05}$	N.S.	15.45	N.S.	2.38	N.S.

Each value represents the mean of three replicates. The values within a column with different letters are significantly different at $P \leq 0.05$ according to the Student's t-test. N.S.: Non-significant.

Table 4. Effects of UV-C treatments on the titratable acidity (TA), total phenolic contents (TPC), total antioxidant capacity (TAC), total monomeric anthocyanin (TMA), and polygalacturonase activity (PG) of '0900 Ziraat' sweet cherry fruits during cold storage (second year)

	TA (%)	TPC (mg/100g)	TAC (µmol/g)	TMA (mg/100g)	PG (mmol/kg/h)
Day 0	0.508 a	42.74 lm	96.10 b-e	24.94 d-j	0.87
Day 7					
Control	0.461 def	60.52 jkl	79.45 f-l	21.08 h-k	0.86
MAP	0.472 b-e	52.28 jkl	66.33 m-s	15.01 lm	0.87
5 min UV-C	0.496 ab	50.70 kl	61.07 p-s	15.71 klm	0.88
10 min UV-C	0.491 a-d	35.33 m	55.96 rs	13.78 m	0.89
20 min UV-C	0.449 efg	37.00 m	53.73 s	16.40 klm	0.84
30 min UV-C	0.464 cde	52.28 jkl	57.76 qrs	20.39 i-l	0.92
Day 14					
Control	0.421 g-j	75.06 e-h	80.96 f-k	29.90 a-e	0.92
MAP	0.430 ghi	75.89 e-h	84.66 e-j	23.56 g-j	0.96
5 min UV-C	0.434 fgh	43.85 lm	61.86 p-s	20.80 h-k	0.87
10 min UV-C	0.492 abc	65.24 g-j	78.10 g-m	24.11 f-j	0.88
20 min UV-C	0.431 f-i	61.26 ijk	70.47 k-q	20.80 h-k	0.99
30 min UV-C	0.427 ghi	75.89 e-h	89.15 d-i	15.57 klm	0.98
Day 21					
Control	0.373 lmn	77.74 d-g	71.50 k-p	30.72 abc	1.06
MAP	0.403 i-l	86.63 cde	57.19 rs	25.08 c-i	0.92
5 min UV-C	0.403 i-l	69.22 f-i	64.98 n-s	28.38 a-g	0.98
10 min UV-C	0.408 h-k	68.39 f-i	67.52 l-r	28.52 a-g	1.06
20 min UV-C	0.402 i-l	80.89 def	63.97 o-s	19.29 j-m	0.08
30 min UV-C	0.388 klm	86.63 cde	73.74 j-p	26.18 b-h	0.10
Day 28					
Control	0.349 nop	101.81 b	94.55 cde	33.20 a	1.11
MAP	0.388 klm	73.39 e-i	90.41 d-h	32.65 a	0.92
5 min UV-C	0.373 lmn	78.48 d-g	98.10 bcd	30.04 a-e	0.96
10 min UV-C	0.403 i-l	72.09 f-i	71.55 k-p	31.69 ab	0.88
20 min UV-C	0.392 jkl	63.85 h-k	77.66 h-n	24.52 e-j	0.95
30 min UV-C	0.418 h-k	73.39 e-i	76.67 i-o	24.39 e-j	0.92
Day 35					
Control	0.324 p	116.63 a	114.85 a	29.48 a-f	0.94
MAP	0.340 op	96.26 bc	107.47 abc	34.03 a	0.84
5 min UV-C	0.340 op	80.89 def	90.93 d-g	30.31 a-d	0.89
10 min UV-C	0.360 mno	91.17 bcd	100.02 bcd	33.76 a	0.90
20 min UV-C	0.351 nop	102.37 b	108.04 ab	21.08 h-k	0.88
30 min UV-C	0.344 nop	96.26 bc	92.27 def	22.32 hij	0.82
$LSD_{0.05}$	0.03	13.57	12.95	5.77	N.S.

Each value represents the mean of three replicates. The values within a column with different letters are significantly different at $P \leq 0.05$ according to the Student's t-test. N.S.: Non-significant.

Decay rate

Decay rates of the sweet cherry fruits during the 2018 and 2019 experimental years have been illustrated in Figure 1A and Figure 1B, respectively. Up to the 14th d of the storage duration, there were no decayed fruits including nontreated control fruits for both years. However, remarkable amounts of the decayed fruits were detected after the 14th d with a more pronounced value in the first year. On the 28th d of the first year, the decay rate in control fruits dramatically increased to 19.03%, followed by the MAP (10.39%) while the 10 min UV-

C resulted in the lowest decay rate (1.19%). At the end of the storage, the decay rate values ranged from 22.57% (control) to 3.03% (10 min UV-C). In the second year, decay rates were at reasonably low levels up to the end of the storage where a sharp increase was determined in control fruits (13.041%). On the other hand, the lowest decay rate occurred in fruits treated with 30 min UV-C (4.52%) which was followed by 5 min UV-C (5.35%) and (6.78%) with close values.

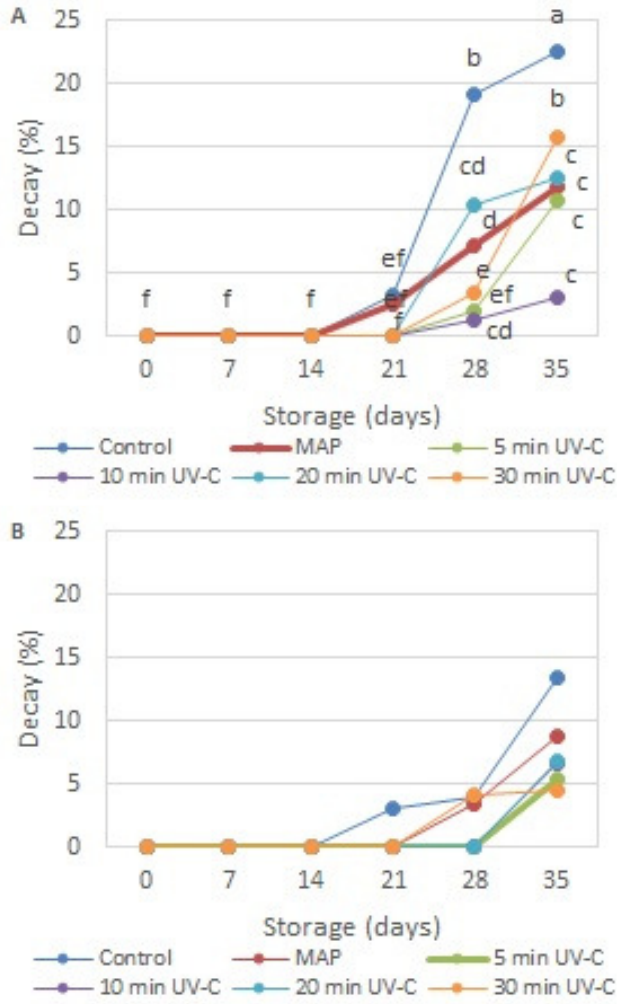

Figure 1. Effects of UV-C treatments on the decay of '0900 Ziraat' sweet cherry fruits during cold storage (A and B; first and second year, respectively)

Phytopathogenic inoculations of the fruits are among the predominating causes of postharvest decay incidence of perishable vegetables and fruits. Sweet cherry is one of the perishable fruits susceptible to pathogen inoculation and subsequent decay. UV-C treatments have been used to degrade the DNA structure of the pathogens on the surface of the crops (Pinheiro *et al*., 2015). UV-C irradiation also induces systemic resistance to harmful microorganisms in crops (Urban *et al*., 2016). The activation of the plant defense mechanism may trigger the accumulation of phytoalexin substances and other phytochemical compounds such as carotenoids and vitamin A all of which induces resistance in fruits against harmful pathogens (Turtoi, 2018). By these mechanisms, the decay incidence of the crop's during storage is decreased as was found in the present study. In mango fruits, postharvest 10 min of UV-C treatment was found capable of suppressing the rot-causing pathogens by inducing the putrescine and spermidine synthesis in the fruits during the storage (González-

Aguilar *et al*., 2001). In the present study, 5 and 10 min of UV-C treatments were more effective in delaying the decay rate in sweet cherries stored in the cold for 35 d. In a similar study conducted by Koçak and Bal (2017) UV-C treatment also remarkably decreased the decay rate of '0900 Ziraat' sweet cherry compared to the control during the storage. The visual quality of perishable products like sweet cherries is directly affected by pathogen inoculations. Indeed, González-Aguilar *et al*. (2007) stated that 5 and 10 min of UV-C treatments in mango fruit had better appearance scores compared to the control with a tight relation to decay rate.

Conclusions

Considering the overall findings of the study, UV-C treatments were effective in reducing weight loss, protecting firmness value and visual quality, and slowing down biochemical changes in '0900 Ziraat' cherry during 35 d of storage at 1 °C compared to control. Among the doses, 10 min UV-C treatments had more promising results, while 5 min of UV-C treatment was not sufficient enough to effectively protect the quality parameters. Besides, 30 min of UV-C treatment was not found appropriate since it caused browning, especially in the fruit pedicel. To sum up, postharvest 10 min of UV-C treatment might be recommended to extend the postharvest quality of '0900 Ziraat' sweet cherries by reducing weight loss and delaying the changes in the physical and biochemical features of the fruits during storage.

Authors' Contributions

Both authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

This study was supported by Scientific Research Project Coordination (BAP) of Selcuk University (Türkiye) with project number 17201107.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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