

RESEARCH ARTICLE

Different Doses of UV-B Treatments Increase Total Soluble Phenols and Anthocyanin Content of Ereğli Black Carrot (*Daucus carota* L. spp. *sativus* var. *atrorubens* Alef.) During Storage

Mehmet Feridun Aztekin¹  • Rezzan Kasım^{2*}  • Mehmet Ufuk Kasım² 

¹Republic of Turkey Ministry of Agriculture and Forestry, Kocaeli Provincial Directorate of Agriculture and Forestry, Kocaeli/Turkey

²Kocaeli University, Faculty of Agriculture and Natural Sciences, Department of Horticulture, Kocaeli/Turkey

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ABSTRACT

In the study, the effect of different doses of ultraviolet-B (UV-B) irradiation on the biochemical quality of Ereğli Black Carrot (*Daucus carota* L. spp. *sativus* var. *atrorubens* Alef.) investigated, during storage. For this purpose, the carrot roots treated with 0 kJ m⁻² (control), 1.575 kJ m⁻² (15m), 3.15 kJ m⁻² (30m) and 6.30 kJ m⁻² (60m) doses of UV-B were placed into the 1 kg sized PE bag and then stored in a cold room at 4 ± 1°C temperature and 85-90% relative humidity for 5 months. In the present study, it is found that even if UV-B applications increased the amount of total soluble phenol content (TSP) of carrots 1.16-1.53 fold during the first month of the experiment, later the amount of TSP decreased. During the storage period, the amount of TSP content changed between 23.72 and 51.11 mg CAE 100 mL⁻¹. While the lowest amount of anthocyanin has obtained from the control application with 557.76 mg kg⁻¹ FW, the highest value measured in UV-B 30m with 1636.96 mg kg⁻¹ FW. As a result of the study, it has determined that UV-B radiation of 3.15 kJ m⁻² dose could be used to increase the anthocyanin content of black carrots.

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Introduction

Carrot is one of the important vegetable species due to its high nutritional value and its ability to be used for various purposes. Carrot (orange) planting area and production amounts have increased in the last ten years in Turkey. The carrot production area is 123 403 in 2009, whereas it reached 125 772 decares in 2019. Similarly, carrot production, which was 593.628 tons in 2009, was 663 882 thousand tons in 2019 (TUIK, 2020). Also, the production area and quantity of black carrots that have been geographically labeled as Ereğli Black Carrot has increased in the last ten years; 72 thousand tons of

production has made on 18 thousand decares area in 2008, while the cultivation area reached 25 thousand decares and the production amount reached 100 thousand tons in 2017 (GTHB-IVA, 2017).

Black carrots are rich in nutrient content, and contain 87.66 g 100 g⁻¹ water, 8.01 g 100 g⁻¹ carbohydrate, 1.85 g 100 g⁻¹ glucose, and 0.14 g fructose per 100 g. Because the black carrot has very low oil content (0.14 g), its energy is only 0.14 kcal which is very low. The black carrot has Niacin (1.21 mg 100 g⁻¹) and Vitamin-B6 (0.072 mg 100g⁻¹), whereas it does not contain vitamin A (TürKomp, 2018).

* Corresponding author

E-mail address: rkasim@kocaeli.edu.tr

Black carrot is a root vegetable that rich in polyphenols, especially anthocyanin and phenolic acid. Anthocyanin, the color of black carrot, is an important compound for health due to its antioxidant effect. Although black carrot is an important anthocyanin source, it is generally not consumed fresh. It used as a processed product such as turnip juice and used as a source of natural food coloring (Kamiloğlu et al., 2017).

The anthocyanins in the flavonoids group dissolve in water and produce different colors depending on the pH of the environment. In general, anthocyanins deposited in the vacuoles of the epidermal and mesophyll cells of plants also defined as secondary metabolites formed in plants under different stress conditions. Anthocyanins also found in dark fruits such as grape berries and blood oranges, as well as vegetables such as red cabbage, radish, fennel, eggplant, and black carrots (Aztekin and Kasım, 2017).

It found that black carrot contains acidified cyanidin 3-glycosylgalactocytose, sinapic acid, ferulic acid, and coumaric acid from anthocyanins (Montilla et al., 2011). It determined that the total phenolic and flavonoid contents of black carrot are 270.74 mg GAE 100 g⁻¹ and 94.38 mg CAE 100 g⁻¹ fresh weight, respectively, so the carrot is an important vegetable in this respect. The amount of cyanide 3-glycoside found in black carrot determined as 2430.45 mg kg⁻¹. Besides, the antioxidant activity of carrot found as 27.75 and 60.70 µmol Trolox g⁻¹ by FRAP and CAPRAC analyzes. It found that this high total phenolic, anthocyanin, and antioxidant capacity of carrot is equivalent to grape and blue nuts (Khandare, 2008)

Ultraviolet (UV) light present in the non-ionizing part of the electromagnetic spectrum and constitutes 8-9% of the total sunlight (Coohill, 1989; Frederick, 1993). Ultraviolet radiation divides into four groups according to wavelengths. One of them UV-V (Vacuum UV, 100-200 nm) occurs in a vacuum medium and is absorbed by all substances. Although UV-C (200-280 nm) is very harmful to living organisms, it is not present in natural sunlight. UV-C is used for surface disinfection of horticultural crops after harvest. UV-B (280-320 nm) constitutes 1.5% of the total spectrum but can cause various harmful effects on plants. UV-A (320-400 nm) constitutes 6.3% of the sunlight on the earth and considered as the least harmful light among UV light spectrum (Hollosy, 2002; Koutchma, 2009).

When UV-B light causes stress in plants, the number of reactive oxygen species (ROS) is produced by the plant increases. The ROS causes damage to DNA, proteins and photosynthetic organs. However, these stress induced metabolites also activate the defense mechanism of the plant. As a result, the flavonoid content of plant increases so that reduces the activity of the plant ROS. Therefore, UV-B stress conditions cause an increase in flavones and anthocyanins content in most of the plant organs (Falcone-Ferreyra et al., 2012).

In the studies, it determined that UV-B light applied to different fruit and vegetable species in the post-harvest period increased the amount of flavonoid and anthocyanin as a result of a defense mechanism in plants. It found that UV-B application after harvest increased the amount of anthocyanin in apples (Hagen et al., 2007), nectarines (Ravaglia et al.,

2013), Europe (*Pyrus communis* L.) and Chinese pears (*Pyrus pyrifolia* Nakai) (Qian et al., 2013). This study aimed to determine the effects of postharvest UV-B light treatments at different doses on total soluble phenol, anthocyanin, and sugar of Eregli Black Carrot during cold storage.

Materials and Methods

Plant Material

Eregli Black carrot was used as plant material in the experiment. Carrot roots were harvested in October and brought to Kocaeli province within 24 hours and applications made after they classified in terms of size. Uniform carrots (The upper diameter: 30±2 mm, the length; 20±2 cm) were used in the study, bruised or broken carrots were not included in the experiment.

Ultraviolet-B (UV-B) Application Device

The ultraviolet application device comprises a wooden bench with three stainless steel reflectors and ultraviolet B light lamps (TL 40 W/12 RS Philips, Holland). The lamps have opened for at least 15 minutes to stabilize the light activity, then the carrot roots were placed into the apparatus. The carrot roots were placed under the lamps with a distance of 30 cm between them. UV-B light applied to carrots in two directions. The carrots placed under the apparatus were returned on after applying light to one apply to the other surface. UV-B was applied to carrots at the storage temperature (4±1°C) to prevent the effect of heat emitted from the lamp. The intensity of the light produced by UV-B lamps on the carrot was measured with a radiometer (Kasım and Kasım, 2015). UV-B applications are as follows.

K: Control,

15m: UV-B for 15 min (1.575 kJ m⁻²);

30m: UV-B for 30 min (3.15 kJ m⁻²);

60m: UV-B for 60 min (6.30 kJ m⁻²)

Packaging and Storage Conditions

After ultraviolet radiation treatments, three carrot roots were placed in a 1 kg sized polyethylene package. A total of 6 holes, 0.5 cm in diameter, drilled into each package to prevent moisture condensation and carbon dioxide accumulation in the package. Packaged carrots were stored for 5 months in cold room at 4±1°C temperature and 85-90% relative humidity.

Total Soluble Phenol Content

The total soluble phenol content of black carrots were determined by modifying the method used by Gonzalez-Aguilar et al. (2005). Accordingly, 2400 µL of pure water together with 150 µL of folin-ciocaltaeu (1:10) solution was added on 150 µL of carrot juice and shaken for 30-40 seconds then hold for 2-4 minutes. Then 300 µL sodium carbonate (1 N, Na₂CO₃) was added to this mixture, and it kept in a dark environment for 2 hours at 20°C and readings were done with a spectrophotometer (Shimadzu, 1240) at 725 nm. Standard curve: For this purpose, a standard solution was prepared at different concentrations (20-60 mg L⁻¹) and the standard curve

is drawn. Total phenolic content was calculated as caffeic acid equivalent (CAE) mg 100 mL⁻¹.

Total Anthocyanin Content

One gram of carrot sample was homogenized by adding 10 mL of the first buffer solution (pH = 1) (125 mL of 0.2 M KCl + 375 mL of 0.2 M HCl) and then centrifuging at 5000 rpm for 15 minutes at 4°C then reading at 510 nm at the spectrophotometer. After 1 g sample was taken again, 10 mL of second buffer solution (pH = 4.5) (400 mL of 1 M sodium acetate 240 mL of 1 M HCl 360 mL of water) was added and homogenized. The extract then was centrifuged at 5000 rpm for 15 minutes at 4°C. After this, the liquid portion was collected and read at 510 nm. The total amount of anthocyanin was calculated by the following formula (mg kg⁻¹ FW).

$$TAC (mg\ kg^{-1}FW) = \frac{(ABS\ pH:1.0 - ABS\ pH:4.5) \times 484.82 \times 1000}{24825 \times DF} \quad (1)$$

In the formula: The part in parentheses indicates the difference in absorbance between pH 1.0 and pH 4.5 at 510 nm; 464.82: the molecular mass of cyanidine-3-glycoside chloride, 24825: molar absorptivity of cyanidine-3-glycoside chloride in solution (pH = 1.0 at 510 nm), DF: dilution factor.

Sugar Analysis

Fifteen mL of distilled water was added on three grams of grated carrots, homogenized, and filtered using by Whatman No. 1 filter paper. Readings were performed with HPLC (Agilent, HP 1260, Hewlett Packard, CA/USA) used 20 µL of the filtrate. HPLC conditions: Column: Zorbax Carbohydrate column, 4.6 mm ID × 150 mm (5 LL); Mobile phase: 75:25 acetonitrile:water. Flow rate: 1.4 mL min⁻¹., Temperature: 30°C, Detector: B HP110 RID, Sample volume; 20 µL in 50:50 acetonitrile:water mixture (Kasım and Kasım, 2015). The amounts of fructose, glucose, and sucrose contained in the carrots were calculated as (%) using the standard curve.

Color Measurement

Color measurements was carried out using Minolta CR 400 Chroma portable colorimeter with the D65 illumination (Minolta Co., Osaka, Japan) at three different points on three carrots in each replicate. Root color determined by L*, a*, b* color space coordinates (CIELAB). Color meter calibrated with a white standard calibration plate (McGuire, 1992; Lancaster et al. 1997). Besides, using the obtained a* and b* color data, Hue (h°) angle was calculated according to the formula:

$$h^{\circ} = \tan^{-1} \frac{b^*}{a^*} \quad (2)$$

Total Soluble Solids (TSS) Content

The amount of TSS was measured in carrot juice using Atago DR-A1 digital refractometer (Atago Co. Ltd. Japan) as refers (%) (Kasım and Kasım, 2017)

Electrolyte Leakage

0.5 mm thick discs were sampled from the carrots to determine electrolyte leakage and placed in 180 mL sized polyethylene terephthalate cups. After washing the carrot discs twice with 50 mL of distilled water, 50 mL of water was

added again and incubated for two hours. The electrical conductivity (EC) of the solution was determined at the end of this period, and then the same samples frozen in the freezer. EC was measured again after the samples taken from the freezer thawed and their temperature reached about 18°C. The amount of electrolyte leakage was calculated by proportioning the last measured EC values to the first measured values and expressed as (%) (Kasım and Kasım, 2016).

Weight Loss

Weight loss (WL) measurements were made with on the same samples at the beginning of the experiment and each analysis period. WL in carrot roots was calculated according to the following formula and expressed as (%).

$$WL (\%) = \frac{\text{Initial weight} - \text{Weight in th analysis period}}{\text{Initial weight}} \times 100 \quad (3)$$

Statistical Analysis

The experiment was established, carried out, and evaluated according to a randomized plot design with four replications and three carrot roots per replica. All data in the study were subjected to variance analysis using SPSS 16 package program, and the differences between the averages were analyzed by using Duncan multiple comparison tests within 5% error limits with the same program.

Results and Discussion

Total Soluble Phenol Content

In the experiment, the total soluble phenol (TSP) amount in carrot roots was measured as 33.48 mg 100 mL⁻¹ CAE at the beginning of storage. The highest amount of TSP recorded in the first month of the trial (51.11 mg 100 mL⁻¹ CAE), and after this, it decreased in all treatments and ranged between 25.93-26.53 mg 100 mL⁻¹ CAE at the end of storage period (Figure 1). During the experiment, the lowest TSP content was determined in K treatment with 23.72 mg 100 mL⁻¹ CAE, while the highest value was found in 30m application with 51.11 mg 100mL⁻¹ CAE. However, the difference between the treatments in terms of TSP content during the experiment was found statistically insignificant at p<0.05 level. Abiotic stress factors could positively affect the biochemical properties of the products. Cold storage could also show a stress effect on products and increase the secondary metabolites in response to this stress. As a matter of fact, in a study where purple carrots stored for 6 months at 0-1°C temperature and 97% relative humidity conditions, it was determined that the content of phenolic substances of carrot roots increased (Gajewski et al., 2010). In the present study, it was determined that the total soluble phenol content of Eregli Black carrot increased in all treatments in the first month of storage. However, the highest increase found in 30m and 60m UV-B applications. Thus, it was observed that both cold storage and UV-B treatments are effective in increasing the TSP content of black carrot even higher doses of UV-B caused an increase in the TSP content. However, TSP content showed decreasing in all treatments after the first month of storage, and it is thought to be this caused by the degradation of

phenols as a result of metabolic activity. Montilla et al. (2011) found that the TSP content of different black carrot varieties such as Antonia, Beta Sweet, Deep Purple, and Purple Haz were different, and varied between 17.9-97.9 mg gallic acid equivalent (GAE) 100 g⁻¹ FW. In our study, the amount of TSP in Eregli Black carrot during storage varied between 23.72 and 51.11 mg CAE 100 mL⁻¹, and therefore it was agreed with the previous study. However, in another study, the total phenolic content of black carrots was found to be between 248.07 mg 100 g⁻¹ FW and 2185.72 mg 100 g⁻¹ FW (Zadernowski et al. 2010). Also, Karakaya et al. (2001) found that the total amount of soluble phenol in purple carrot juice was 772±119 mg L⁻¹. Because the black carrot used in this study is not a cultivar, so the color of inner tissues has varied from orange to black, furthermore the proportion of orange/purple/black very changeable. Therefore it could be said that the difference of the TSP content of carrots in our study than these two studies has arisen different plant material using in the experiment.

Sharma et al. (2012) stated that the phenolic substances are mostly concentrated in the periderm tissues of carrots and therefore the most phenolic substances accumulated in the skin (54.1%), followed by phloem tissue (39.5%) and at least in xylem tissue (6.5%). In this study, the highest total soluble phenol content found as 51.11 mg CAE 100 mL⁻¹. It determined that ultraviolet-B (UV B) irradiation treatments at doses of 1.3-5.9 kJ m⁻² did not affect the amount of TSP in whole products such as strawberry, blueberry, grape, cherry tomato, sweet corn, sweet potato by Du et al. (2014). Also, the authors suggest that the TSP content of fresh-cut lettuce and wild carrot increased 1.2-2.3 times 3 days after UV-B light application (Du et al. 2014). In the present study, UV-B applications at doses of 1.575 kJ m⁻² (15m), 3.15 kJ m⁻² (30m) and 6.30 kJ m⁻² (60m) to Eregli Black carrot increased the TSP content of carrots by 1.16, 1.53 and 1.52 times in the first month of the storage, respectively. These results are agreed with the previous study by Du et al. (2014).

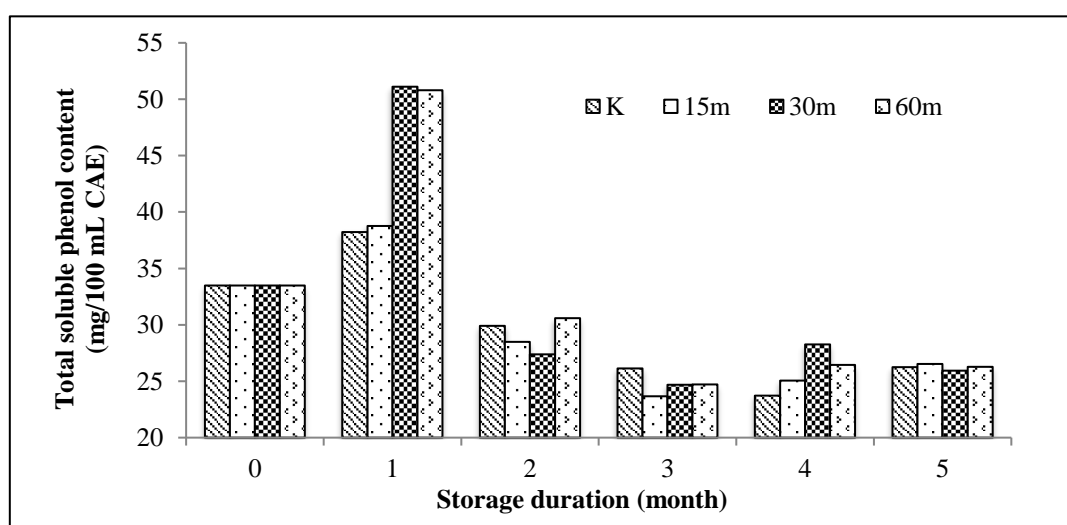


Figure 1. Variation of total phenol content during storage in Eregli Black Carrot treated with different doses of ultraviolet-B (UV-B). The difference between the means of treatments is statistically insignificant

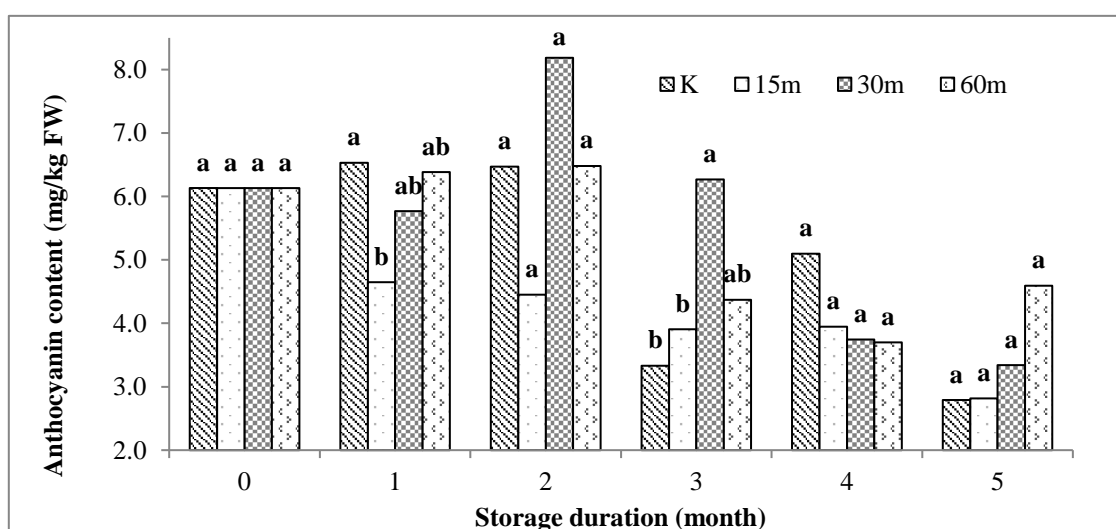


Figure 2. Variation of the anthocyanin content during storage in Eregli Black Carrot treated with different doses of UV-B. Means with different letters are significantly different at the 0.05 level

Total Anthocyanin Content

In the study, the total amount of anthocyanin measured as 613.42 mg kg⁻¹ FW at the beginning of storage, generally decreased in all treatments and ranged between 557.76-918.67 mg kg⁻¹ FW at the end of storage (Figure 2). However, the differences between the treatments was found to be statistically significant ($p < 0.05$) in the first and third months. Besides, the carrots in the 30m treatments had maximum anthocyanin content and followed by 60m, K, and 15m treatments. Therefore, it could say that high doses of UV light caused an increase in the amount of anthocyanin of Eregli Black carrot. Guo et al. (2008) stated that light is one of the most important environmental factors that regulate the expression of genes that provide plant growth, and ultraviolet

lights that make up 7% of rays coming to the earth can reveal different reactions in plants. Researchers have also said that both UV-A and UV-B can increase anthocyanin accumulation by stimulating anthocyanin biosynthesis genes. Similarly, in the study, it was found that UV-B applications, especially in high doses, increased the amount of anthocyanin in black carrots compared to control. The amount of anthocyanin in black carrots was found to range from 44.25 mg 100g⁻¹ (Zadernowski et al., 2010) to 168.7 mg 100 g⁻¹ FW (Assous et al. 2014). In the present study, the lowest anthocyanin content calculated in the control group (557.76 mg kg⁻¹ FW), while the highest value determined in 30m treatment (1636.96 mg kg⁻¹ FW). Therefore, the results were consistent with previous studies.

Table 1. The TSS (%), fructose (mg kg⁻¹), glucose (mg kg⁻¹), and sucrose (mg kg⁻¹) values of black carrot during storage

| | Storage duration (Month) | K | 15m | 30m | 60m | Average |
|----------|--------------------------|-----------|------------|------------|------------|------------|
| TSS | 0 | 11.61 a** | 11.61 a | 11.61 a | 11.61 a | 11.61 B* |
| | 1 | 13.03 a | 11.53 b | 12.51 ab | 13.34 a | 12.60 A |
| | 2 | 12.28 ab | 11.33 b | 11.33 b | 12.80 a | 11.93 AB |
| | 3 | 12.45 a | 10.85 a | 12.15 a | 11.68 a | 11.78 AB |
| | 4 | 11.83 a | 11.25 a | 12.40 a | 11.63 a | 11.78 AB |
| | 5 | 11.50 a | 10.80 a | 11.58 a | 11.63 a | 11.38 B |
| | Average | 12.11 A | 11.23 B | 11.93 A | 12.11 A | |
| Fructose | 0 | 135.48 a | 135.48 a | 135.48 a | 135.48 a | 135.48 C |
| | 1 | 711.06 a | 781.23 a | 941.03 a | 826.36 a | 814.92 B |
| | 2 | 787.43 a | 749.18 a | 963.30 a | 950.94 a | 862.71 B |
| | 3 | 845.79 a | 928.48 a | 1216.17 a | 857.67 a | 962.03 AB |
| | 4 | 779.20 a | 959.81 a | 887.96 a | 781.69 a | 852.16 B |
| | 5 | 1274.17 a | 963.90 a | 1075.52 a | 1057.66 a | 1092.81 A |
| | Average | 755.52 A | 753.01 A | 869.91 A | 768.30 A | - |
| Glucose | 0 | 628.46 a | 628.46 a | 628.46 a | 628.46 a | 628.46 D |
| | 1 | 1652.54 a | 1898.07 a | 2191.05 a | 1998.00 a | 1934.91 C |
| | 2 | 1866.17 a | 1973.10 a | 2534.41 a | 3012.21 a | 2346.47 BC |
| | 3 | 2607.12 a | 2768.49 a | 3388.83 a | 2644.75 a | 2852.30 A |
| | 4 | 2671.12 a | 3372.10 a | 2914.68 a | 2565.26 a | 2880.79 A |
| | 5 | 3104.55 a | 2637.31 a | 2452.07 a | 2644.73 a | 2709.67AB |
| | Average | 2088.33A | 2212.92 A | 2351.58 A | 2248.90 A | |
| Sucrose | 0 | 5946.29 a | 5946.29 a | 5946.29 a | 5946.29 a | 5946.29 A |
| | 1 | 5056.58 a | 4066.97 a | 4359.97 a | 5428.38 a | 4727.97 B |
| | 2 | 4387.34 a | 4059.18 a | 3908.51 a | 4271.62 a | 4156.66 B |
| | 3 | 3825.31 a | 2594.71 a | 2597.18 a | 2923.18 a | 2985.10 C |
| | 4 | 4829.07 a | 4423.89 a | 3538.20 a | 4218.75 a | 4252.48 B |
| | 5 | 3611.86 a | 2323.05 b | 2514.98 ab | 3090.32 ab | 2885.05 C |
| | Average | 4609.41 A | 3902.35 AB | 3810.86 B | 4313.09 AB | |

*The capital letters indicate a significant difference at the $p < 0.05$ level between the application or time averages.

**The lower-case letters indicate a significant difference at $p < 0.05$ level between applications.

Total Soluble Solids (TSS) Content

In the present study, the TSS content of black carrots ranged between 10.85-13.34% during storage (Table 1). In general, however, the TSS content of black carrots in K, 30m, and 60m treatments increased, whereas it decreased in 15m treatment compared to an initial value in the first month of the storage. In this respect, it was found that the difference between K and 60m or 15m treatment was statistically significant ($p < 0.05$). The highest TSS was measured from 60m application with 11.63% and followed by 30m, K, and 15m treatments at the end of the storage period. In the study, the carrots had the least TSS in 15m treatment, whereas the TSS in carrots treated with 60m was higher than the other applications in the first two months but then decreased. In a

study, the TSS content of orange and purple carrots tended to increase during the storage period of 6 months at 0-1°C temperature and 97% relative humidity (Gajewski et al., 2010). In the present study, in general, although the amount of TSS had firstly increasing and then in a decreasing tendency in all treatments, it remained above the initial value throughout the experiment except 15m application. Therefore, it can be said that the results of the present study similar to Gajewski et al. (2010) findings. It was determined that the water content of orange carrot in the edible portion was 88.29 g 100 g⁻¹, the carbohydrate content was 9.58-10%, and the soluble carbohydrate content varied between 6.6-7.7 g 100 g⁻¹ (Sharma et al., 2012; USDA, 2018). It was also determined that the water content of black carrots was 87.66 g 100 g⁻¹, and the carbohydrate amount was 8.01 g 100 g⁻¹ (TürKomp, 2018). In

our study, the TSS content ranged between 10.80-13.34% during the experiment, especially the 60m treatment was effective in increasing the TSS amount of carrots.

Fructose, Glycose and Sucrose Content

The amount of fructose generally increased in all applications during the trial period. At the beginning of the study, the amount of fructose measured as 135.48 mg kg⁻¹, reached 711.06-941.03 mg kg⁻¹ with an increase of 5-6 times in the first month of the study and changed 963.90-1274.17 mg kg⁻¹ with an increase of 7-9 times at the end of the experiment (Table 1). In general, in all UV-B applications, the amount of fructose was higher than the control until the fourth month of the experiment, whereas in the last month of storage, the amount of fructose of carrots in application K was higher than that of UV-B. The amount of glucose was measured as 628.46 mg kg⁻¹ at the beginning of the study and increased in general during all applications ranging between 2452.07-3104.55 mg kg⁻¹ at the end of the storage (Table 1). However, the difference between the applications in terms of fructose and glucose content found to be insignificant ($p < 0.05$). In contrast to the fructose and glucose, the sucrose content of carrots which was 5946.29 mg kg⁻¹ at the beginning of the study, and decreased in all treatments until the third month of storage, the highest decrease was determined in 15m and 30m treated carrots. However, no significant difference was found between the applications. At the end of the experiment, the sucrose content of black carrots varied between 2323.05-3611.86 mg kg⁻¹. The sugars found in carrot roots have a significant effect on the formation of sweetness and masking of the bitter taste

(Varming et al, 2004). Hui and Evranuz (2012) said that sucrose (49.95 to 331 g kg⁻¹) is the dominant sugar in the composition of black carrots which is grown in Turkey, followed by glucose (6.66 to 56.4 g kg⁻¹), and fructose (6.65 to 43.06 g kg⁻¹). Besides, when the data of TürKomp (2018) examined, it is seen that the glucose content of black carrot was 185 mg kg⁻¹, while the fructose content was 14 mg kg⁻¹. In our study, the content of fructose of black carrots was 135.48-1274.17 mg kg⁻¹, followed by glucose (628.46-3388.83 mg kg⁻¹) and sucrose ranged between 2323.05-5946.29 mg kg⁻¹. It stated, in a previous study, that the total sugar content of black carrots ranged between 5.12% and 7.09% (Hui and Evranuz, 2012), whereas the sugar content of black carrot found as 5.9-52% in dry matter in other studies (Kırca et al., 2007; Kamiloğlu et al., 2017). In the present study, the total sugar content of black carrot ranged between 5.92-8.75% and that of carrots in 30m and 60m treatments found to be higher than in control and 15m applications at the first two months of the experiment. Therefore, in general, it can be said that high-dose UV-B treatments have the effect of increasing the total soluble sugar content. Since UV-B applications create abiotic stress in products, the defense mechanism becoming active and some biochemical changes have occurred. Also, a recent report showed that UVC treatment significantly increased the ratio of total soluble sugars to total organic acid, which was achieved by up-regulation expressions of nicotinamide dinucleotide phosphate-malic enzyme (NADP-ME) and of phosphoenolpyruvate carboxykinase (PEPCK) gene (Onik et al., 2019). It thought that UV-B treatment increases total sugars as a result of this mechanism.

Table 2. The L^* , a^* , b^* , and h° values of black carrot during storage

| | Storage duration (Month) | K | 15m | 30m | 60m | Average |
|-------------------|--------------------------|------------|-----------|-----------|----------|----------|
| L^* | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1 | -10,11 a** | -7,77 a | -4,20 a | -3,56 a | -6,41 B* |
| | 2 | 0,42 a | -4,34 a | -0,76 a | -5,78 a | -2,61 AB |
| | 3 | -1,15 a | -3,48 a | -4,32 a | -7,08 a | -4,01 B |
| | 4 | -1,01 a | -6,18 a | -4,78 a | -6,59 a | -4,64 B |
| | 5 | -4,00 a | -4,00 a | -1,03 a | -8,90 a | -4,48 B |
| | Average | -2,64 A | -4,30 A | -2,52 A | -5,32 A | |
| a^* | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1 | 1,54 a | 3,50 a | 0,39 a | -7,19 a | -0,44 A |
| | 2 | -14,28 a | 4,31 a | -10,86a | 0,88 a | -4,99 A |
| | 3 | -16,97 a | 17,26 a | -14,20 a | -5,10 a | -4,75 A |
| | 4 | -22,40 a | 0,51 a | -13,50a | 2,06 a | -8,34 A |
| | 5 | -20,19 a | 0,23 a | -21,73 a | -7,56 a | -12,31 A |
| | Average | -12,05 B | 4,30 A | -9,98 B | -2,82 AB | |
| b^* | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1 | 7,07 b | 65,36 b | 332,58 ab | 588,9 a | 248,48 A |
| | 2 | 46,64 b | 126,32 ab | 354,94 ab | 646,26 a | 293,54 A |
| | 3 | 19,56 b | 123,55 b | 243,69 ab | 695,83 a | 270,66 A |
| | 4 | 60,32 b | 191,66 b | 250,83 b | 722,25 a | 273,01A |
| | 5 | 38,75 a | 168,87 a | 383,88 a | 768,73 a | 340,06 A |
| | Average | 28,72 C | 112,63 CB | 238,82 B | 570,33 A | |
| Hue (h°) | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1 | -3,51 b | 46,29 b | 291,05 ab | 484,10 a | 204,48 B |
| | 2 | 42,00 b | 86,68 b | 307,54 ab | 486,01 a | 230,56 B |
| | 3 | 39,41 b | 82,78 b | 237,72 ab | 545,94 a | 226,46 B |
| | 4 | 56,92 b | 125,45 b | 222,80 ab | 533,94 a | 209,78 B |
| | 5 | 44,91 b | 114,36 b | 399,13 ab | 562,15 a | 280,14 B |
| | Average | 29,96 C | 75,93 C | 226,37 B | 435,36 A | |

*The capital letters indicate a significant difference at the $p < 0.05$ level between the application or time averages.

**The lower-case letters indicate a significant difference at $p < 0.05$ level between applications.

The Change Rate of L^* , a^* , b^* and Hue Angle Value

The carrot color change rates were calculated from L^* , a^* , b^* color values of black carrot roots measured, were shown in Table 2. According to these data, the highest L^* color change was found in the control group (-10.11%) in the first month of the study, and followed by 15m (-7.77%), 30m (-4.20%) and 60m (-3.56%) treatments. However, the differences between control and UV-B treatments were not found to be statistically significant ($p < 0.05$). After this period, the change rates in L^* value of carrots in 60m treatment increased but decreased in all other treatments until the end of the storage. Therefore it could be said that the L^* color values of the carrot in the 60m treatment showed more decrease than the others (Table 2). In the study, a^* values of carrots in control and 30m treatments decreased during the trial period, whereas it decreased then increased until the third month of storage in carrots in 15m application. In contrast, the 60m treatment did not affect a^* color change, and the color of these carrots maintained close to the initial values (Table 2). In the study, although the increase occurred in the b^* value change rates of carrots in all treatments at the first month of storage (Table 2), the highest increase was recorded in 60m application (588.9%) and followed by 30m (332.58%), 15m (65.36%), and K (7.07%). However, while the difference between 60m and 30m application did not find to be statistically significant, a significant difference was found between 60m and K or 15m applications ($p < 0.05$). Table 2 shows the data of the h° value changes in the study. Accordingly, the highest h° value change was determined in the 60m treatment and followed by 30m, 15m, and K treatments during the storage, and the differences between 60m and the other treatments found to be

statistically significant at $p < 0.05$ level. The brightness (L^*), is often related to the quality characteristics of the product and varies depending on the surface structure, the porosity of the surface, the roughness and surface moisture (Gallo et al., 2012). In the present study, L^* values decreased during the first month of storage in all treatments, but the highest decrease was observed in carrots in the control group. However, the maximum change in L^* color values was determined in the 60m application, during the experiment. The decrease in L^* color value indicates that darkening or blackening occurred in color, while the increase also indicates that the color intensity decreases. Accordingly, the decrease in brightness in the 60m application, also means that the black color darkened further. In the research, a^* color values decreased in K and 30m treatments in terms of initial values but decreased after increasing up to the third month in 15m treatment, during storage; in samples in the 60m, it did not show any significant change and remained at almost initial values. The variation of the b^* color values measured in the experiment was similar to the a^* values. Accordingly, the b^* values of UV-B treated carrots at the beginning of the storage were lower than the control samples but increased during the study and the highest increase was found in the 60m application. In the present study, hue angle values increased compared to the beginning, the highest change was determined in the 60m treatment, while the least change was calculated in the K group. Therefore, in K and 15m applications, the color is close to the initial values, while in 30m and 60m applications it increased considerably compared to the beginning. Therefore, it could suggest that UV-B applications cause a change in color, especially at higher doses.

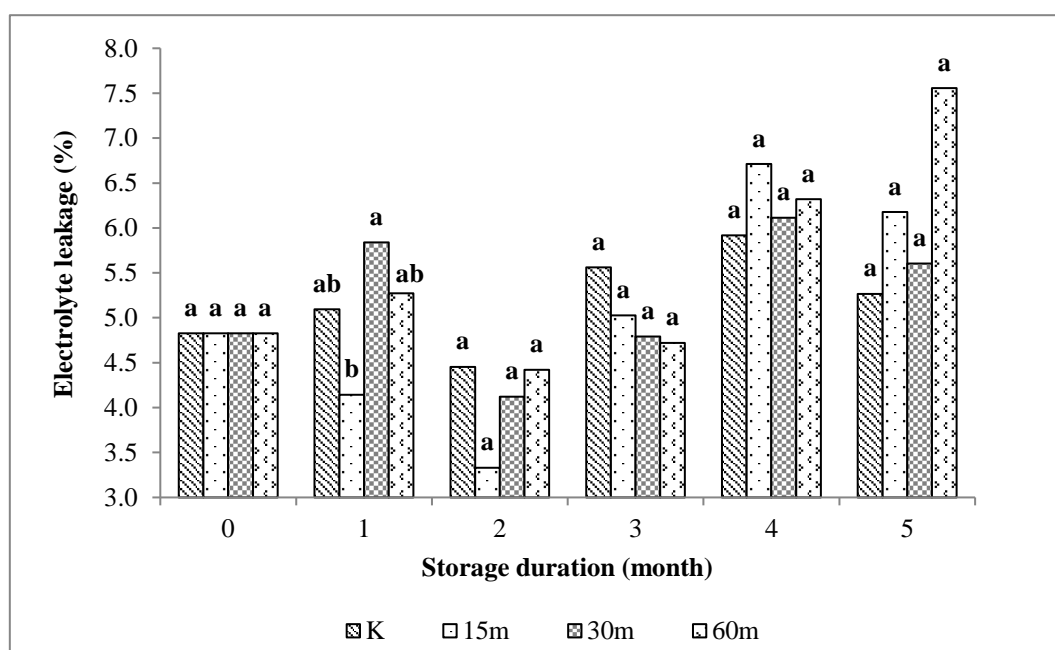


Figure 3. Changes in electrolyte leakage during storage in Eregli Black carrot treated with different doses of UV-B treatment. Means with different letters are significantly different at the 0.05 level

Electrolyte Leakage

In the first month of the study, electrolyte leakage increased in K, 30m, and 60m treatments but decreased in 15m application. While the difference between 15m and 30m application was found statistically significant, the difference between the other applications found to be insignificant (Figure 3). However, it was found that the electrolyte leakage decreased in all treatments in the second month of storage, and after that increased up to the fourth month, but decreased again at the end of the study. Electrolyte leakage was 4.83% at the beginning of the experiment, and it has changed as an increase-decrease in all applications, during storage. At the end of storage, it increased between the initial amount and changed between 5.27-7.56%. Although electrolyte leakage occurs as a plant response to abiotic stresses such as salinity, pathogen attack, drought, heavy metals and ultraviolet radiation, the mechanism and physiological role of this

phenomenon have been clarified recently. Electrolyte leakage reported to mainly associated with K^+ leakage from plant cells mediated by plasma membrane cations (Demidchik et al., 2014). As a result of the ultraviolet radiation (254 nm) treatment, it was determined that different substances from plant cells leaked into the intercellular space (Wright Jr. et al., 1981). Murphy and Wilson (1982) found that the application of 1.680 J m^{-2} short-wave ultraviolet light (254 nm) to rose (*Rosa damascena* var. Gloire de Guilan) cells in washed suspension culture caused K^+ ion leakage in the outdoor environment. In the present study, electrolyte leakage generally increased in all applications during storage. However, the maximum increase was found in the 60m treatment, followed by 30m, K, and 15m applications. According to these results, higher doses of UV-B application increased ion leakage from the cell. The results are consistent with previous studies.

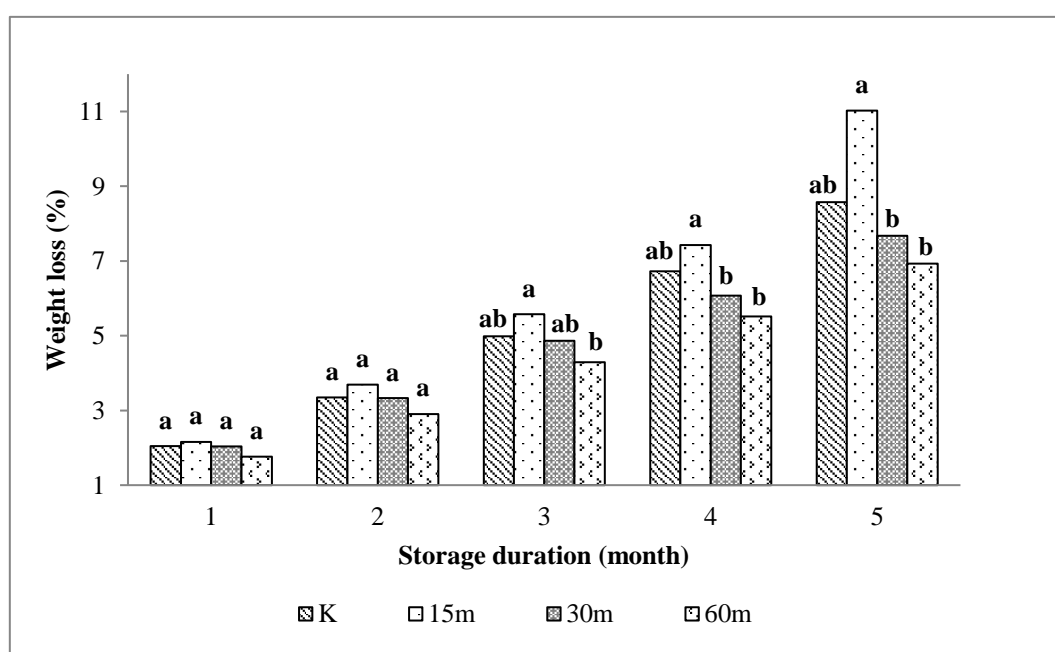


Figure 4. Weight loss changes during storage in Eregli Black carrot treated with different doses of UV-B. Means with different letters are significantly different at the 0.05 level

Weight Loss

The weight loss values of carrots in all treatments increased during storage (Figure 4). However, the highest increase was recorded in 15m (11.03%) treatment and followed by K (8.57%), 30m (7.67%), and 60m (6.93%) applications at the end of the storage. It was found that the difference between 15m and K treatments was insignificant at the $p < 0.05$ level, whereas the difference between 15m and 30m or 60m treatments was significant. The maximum weight loss during storage was found in 15m treatment, while the lowest weight loss was measured in 60m application. Therefore, it was seen that high doses of UV radiation reduced weight loss in carrot roots. The viability of fruits and vegetables persists after harvest, so even if stored at low temperatures, weight losses occur. In this study, although there was a weight loss in all treatments during storage in black carrots, this value ranged

from 1.76 to 11.03%, exceeding the acceptable limit for horticultural crops only in 15m application (Kader et al., 1985). In the 60m UV-B treatment, however, it reached 6.93% at the end of the storage period. Therefore, 30 and 60m UV-B applications can be said to be very effective in controlling weight loss.

Conclusion

Ultraviolet (UV) radiation treatments initially was used for surface disinfection (UV-C) in the post-harvest process of horticultural crops. It was found that UV radiation, especially UV-B lights, was triggered the defense mechanism by creating stress in the plants and caused some biochemical changes. In this study, the effects of different doses of UV-B light applications mainly on phenols and anthocyanins together with other biochemical quality components investigated in Eregli

Black carrot. As a result of the study, it was found that UV-B radiation had a significant effect on total soluble phenol, total anthocyanin, glucose, fructose, and sucrose content and other quality components especially in 30m and 60m treatments. We did not find any studies about the fresh black carrot storage. Therefore, the study is a first in this regard. In this study, it was found that, although the doses examined had a certain effect on the biochemical components of black carrot, this effect decreased with extending storage time. Therefore, it was concluded that the subsequent studies using higher doses would be more beneficial in increasing the amount of these important components in black carrots.

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