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Blue LED lighting improves the postharvest quality of tomato (*Solanum lycopersicum* L. cv. Zahide F_1) fruits

Mavi LED ile aydınlatma domates meyvelerinin (*Solanum lycopersicum* L. cv. Zahide) hasat sonrası kalitesini arttırır

Türkay ARSLAN[1]

Rezzan KASIM[2*]

Mehmet Ufuk KASIM[2]

[1] Kocaeli University, Institute of Natural and Applied Sciences, Department of Horticulture, 41001, Kocaeli, Turkey

[2] Kocaeli University, Faculty of Agriculture Department of Horticulture, 41285, Kartepe-Kocaeli, Turkey

***** Corresponding author (Sorumlu yazar):

rkasim@kocaeli.edu.tr

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ABSTRACT

Objective: The objective of this study was to investigate the effects of different wavelengths of LED lighting on the postharvest quality of tomatoes (*Solanum lycopersicum* L. cv. Zahide) during breaker harvest stages..

Material and Methods: Harvested tomato fruits were placed on 500 g polystyrene foam dishes and wrapped with stretch film. They then were stored in 4±1°C temperature and 85-90% relative humidity for 42 days under the red (R), blue (B), green (G) and white (W) LED light conditions. The fruits stored in the dark were used as control (C).

Results: R and W LED treatments increased hue angle value, yellowness index value, and fruit firmness of tomatoes Blue LED lighting, also decreased electrolyte leakage that indicates delaying senescence. It was also found that blue and red LED lighting delayed fruit decay.

Conclusion: As a conclusion, it could be satated that the blue LED lighting was found to be more effective than the red, white and green LED light in maintaining the quality of the tomatoes harvested at the breaking stage.

Keywords: Color, decay, electrolyte leakage, LED light, storage, tomato

ÖZ

Amaç: Bu çalışmada kırılma döneminde hasat edilen domates (*Solanum lycopersicum* L. cv. Zahide) meyvelerinin farklı dalga boylarındaki LED ile aydınlatılmasının hasat sonrası kalitesi üzerine etkileri araştırılmıştır.

Materyal ve Yöntem: Hasat edilen domatesler 500 g polistiren köpük tabaklara yerleştirilmiş ve üzeri streç filmle sarılmıştır. Ardından meyveler 4±1°C sıcaklık ve %85-90 oransal nem içeren odada, kırmızı (R), mavi (B), yeşil (G) ve beyaz (W) ışık şartları altında 42 gün süreyle depolanmıştır. Karanlıkta depolanan meyveler kontrol (C) olarak kullanılmıştır.

Araştırma Bulguları: R ve W LED uygulamaları, meyvelerin hue açısı, sarılık indeksi ve meyve eti sertliğini arttırmıştır. Mavi LED aydınlatma ayrıca yaşlanmanın geciktiğinin göstergesi olan elektrolit sızıntısını azaltmıştır. Ek olarak mavi ve kırmızı LED aydınlatma meyve çürümelerini geciktirmiştir.

Sonuç: Sonuç olarak, mavi LED aydınlatmanın kırılma döneminde hasat edilen domateslerin hasat sonrası kalitesinin korunmasında kırmızı, beyaz ve yeşil LED ışıktan daha etkili olduğu bulunmuştur.

Anahtar sözcükler: Renk, çürüme, elektrolit sızıntısı, LED ışık, depolama, domates

INTRODUCTION

Although tomato (*Solanum lycopersicum* L.) is classified as botanical fruit, it is considered a vegetable in Turkey and it is rich in fiber, vitamins A and C, lycopene, and other carotenoids (Gharezi et al. 2012) and flavonoids (Lei et al. 2016). Epidemiological studies have shown that the increase in consumption of lycopene i.e tomato reduces the formation of cardiovascular diseases and some types of cancer (Meena et al. 2015). Tomato is one of the most consumed vegetables in the world. According to the FAO 2016 data, the tomato has a share of 13% with 180.8 million tons in the production of fresh vegetables, which is 1.13 billion tons. Turkey has ranked fourth with 12.8 million tons production after China (62.86 million tonnes), and India (19.0 million tons) in World tomato production (FAOSTAT 2019).

Tomato is a climacteric fruit and continues ripening after harvest. This climacteric ethylene rises increasing the taste of the fruit, whereas it also stimulates senescence. So the storage period of tomatoes after harvest is shortened, that this period is limited to 2-3 weeks in fully ripe tomatoes (Gharezi et al. 2012). Therefore, different methods have been used to regulate the time of postharvest ethylene synthesis in tomatoes, such as cold storage, controlled atmosphere storage or modified atmosphere package systems, 1-MCP, ozone treatments, edible coating, and irradiation treatments.

Although irradiation treatments were made with gamma and ultraviolet irradiation techniques at the beginning, in recent years, light-emitting diode (LED) technology also applied for this purpose. In previous studies, it was determined that the blue LED (400 μmol / m^2s; 465 nm) was effective on yellow color formation in citrus fruits (Deng et al. 2016), red LED (50 μmol / m^2s, 660 nm) increased carotenoid accumulation in mandarin (Ma et al. 2012), and also a green LED light increased the chlorophyll content in cabbage and broccoli (Lee et al. 2014).

The LED light treatment is also effective on the biochemical components of fruits and vegetables. Studies have shown that the LED light application affects the amount of phenolic substance. Accordingly, yellow LED (590 nm) in apple, tomato, and red bell pepper, and green LED light application in broccoli (Kokalj et al. 2016) resulted in an increase in the amount of phenolic substance (Ma et al. 2015). LED light applications also increased the anthocyanin content found in fruits and vegetables. The previous studies indicated that blue and green LEDs (500-600 nm, Kanazawa et al. 2012) increased the anthocyanin content of grapes and strawberries (Kim et al. 2011; Kondo et al. 2014; Xu et al. 2014a) respectively

LED light applications reduce the microorganism load on the surface of fruits and vegetables and prolong the storage period of the product. It was found that the application of blue LED light (465 nm, 80μmol / m^2s) on Satsuma mandarins (*Citrus unshiu* Marc.) inoculated with *Penicillium italicum*, showed an antifungal effect against blue mold (Yamaga et al. 2015).

The reactions of fruit and vegetables against LED light applications are different according to the color of the lamp because the effectiveness of lamps of different colors is different due to the wavelength. Therefore, the effectiveness of LED lamps on the post-harvest quality of fruits and vegetables is worth examining for all types, varieties, and the color for each plant. Hence, a study was conducted and the objective of this study was to determine the effects of four different LED light applications such as red, blue, green, and white, in maintaining the postharvest quality of tomato fruits harvested during the breaking period.

MATERIAL and METHODS

Plant material

In this study, Zahide F_1 tomato (*Solanum lycopersicum* L. cv. Zahide F_1) variety was used as plant material. Tomato fruits were taken from the greenhouse of a producer in Bayraktar village, the Izmit district of Kocaeli province. The coordinates of the greenhouse are at 30^o 4'41.97 '' latitude and 40^o

47'9.68 '' longitude, and it is a block greenhouse with 16 m x 50 m dimensions. Tomato seedlings were planted in the greenhouse on the 15th of April, 2017, as in double rows and using 60 x 50 x 90-row spacing and distance, by the grower. The tomato fruits used in experiments were harvested according to Kasım and Kasım (2015) while they were in the breaker stage (when pink or red color dominates at most 10% of the surface), at 11:00 am on the 11th of July 2017. The tomato fruits on the second cluster of plants were used in the experiment. The harvested tomatoes are arranged in a single row in the crates and were quickly (in one hour) transported to Postharvest Physiology Laboratory at Kocaeli University Arslanbey Vocational School.

LED (Light-emitting diode) lighting apparatus

Four different LED apparatuses were prepared as red, blue, green, and white. The apparatuses were made from a wooden frame in the dimensions of 1 m x 1 m x 0.8 m a 5 m LED strip for each color was mounted on each frame. The distance between tomatoes and LED lamps was set at 40 cm. The surroundings of the device were covered with black polyethylene to prevent lights from the outside (Kasım and Kasım, 2017). Tomatoes stored in completely dark were used as controls for comparison purposes.

Red (R), blue (B), green (G), and white (W) LED treatments

After the tomato fruits were packaged, they were placed under the R, B, G, and W LED lighting devices prepared in the cold storage and continuously illuminated during storage. The wavelengths and properties of the LED lights were determined using the Asensetek Lighting Passport Essence device (Figure 1). The photosynthetic photon flow density (PPFD) and photosynthetic photon flow density efficiency (YPFD) values of the LED light sources used are tabulated in Table 1.

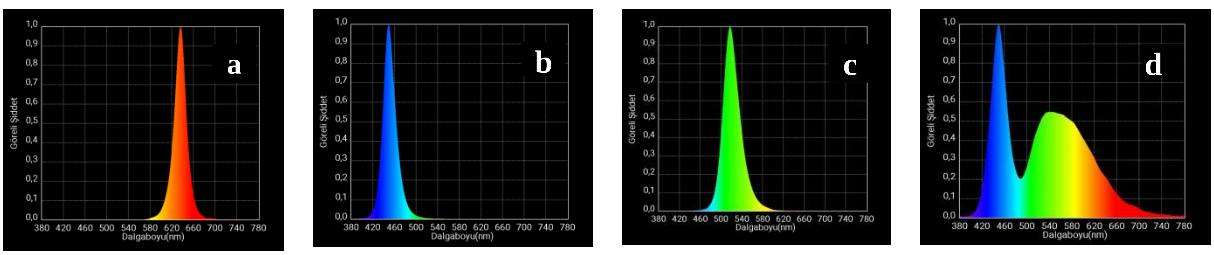

Figure 1. Wavelengths and relative intensities of R (a), B (b), G (c) and W (d) LED lights applied to tomato fruits.

Şekil 1. *Domates meyvelerine uygulanan R (a), B (b), G (c) ve W (d) LED ışıklarının dalga boyları ve bağıl yoğunlukları.*

Table 1. PPFD and YPFD values of the LED light sources used in the experiment

Çizelge 1. *Denemede kullanılan LED ışık kaynaklarının PPFD ve YPFD değerleri*

Light sources	Wavelenght (nm)	PPFD (μmol / m^2s)	YPFD (μmol /m^2s)
R	600-700	2.0256	1.9631
B	400-499	6.8933	5.0702
G	518	3.6520	2.8058
W	449	6.7503	5.5264

Packaging and storage conditions

In the experiment, tomatoes were placed in 500 g of yellow foam dishes as three tomatoes in each and covered with stretch film. Three replications that composed of three packages were used in all treatments. The packaged tomato fruits were placed in a cold storage room with a temperature of 4 ± 1ºC and 85-90% relative humidity and stored for 42 days.

Methods

The total soluble phenol content of tomatoes were found according to the method as used by González-Aguilar et al. (2005). The total soluble phenol content of tomatoes was calculated as the caffeic acid equivalent (CAE, mg / 100 mL) using the standard curve. Color measurements were made on a total of nine fruits in each application, in three different regions of each fruit, using a color meter device (Minolta CR 400 Chroma; Minolta Co., Osaka, Japan) and D65 lighting. L^*, a^*, b^* color space coordinates (CIELAB) have been used to express the fruit color. The colorimeter was calibrated with the instrument's white standard calibration plate (L^* = 97.52; a^* = -5.06; b^* = 3.57) at the start of the measurement (McGuire 1992, Lancester et al. 1997). In addition, by using the obtained data; since $a^* > 0$ and $b^* > 0$, hue angle, according to the formula $h^o = \arctan(b^* / a^*)$ (Kasım and Kasım, 2015). The amount of total soluble solids in tomato juice was measured using Atago DR-A1 digital refractometer (Atago Co. Ltd. Japan) and expressed as (%) (Eroğul and Özmen 2020). The fructose, glucose and sucrose content of tomatoes were determined by the method used by Kasım and Kasım (2015). The amount of fructose, glucose, and sucrose contained in the tomatoes was calculated using the standard curve (%). Titratable acidity was calculated according to Karaçalı (2006). The flesh firmness was measured from the equatorial region of the fruit and three different points at an angle distance of 120º from each other using a digital penetrometer. The measurements were achieved on three fruit of each replicate, and three repetitions were used in each treatment. A device that has a 7.9 mm conical diameter tip was used in the measurements for expressing the flesh firmness (N). The elecktrolyte leakage content of tomatoes was calculated as suggested by Kasım ve Kasım (2017). Weight loss measurements were also made with the same samples at the start of the experiment and in seven days intervals and weight losses were calculated as (%) by proportioning to the initial values. To determine the decay rate, decayed tomatoes in all treatments during each analysis period were determined. The decay rate was calculated by proportioning infected fruits to the total number of fruits and expressed as a percentage.

Statistical analysis

The experiment was established, carried out, and evaluated with three replicates and three fruit for each replicate. The data obtained in this study were then analyzed using the SPSS 16 package program, and the differences between the means were found within the 5% error limits %95 probability level mı olacak? using Duncan multiple comparison test.

RESULTS and DISCUSSION

Total soluble phenol content (TSP, mg / 100 mL CAE): In the study, the amount of TSP increased in all applications during storage (Figure 2). However, the highest TSP was measured in the control group (140.70 CAE) and this was followed by B, W, G, and R (138.74, 138.74, 125.25, 124.86 mg / 100 mL CAE), respectively. Even though the difference between C with R and G treatments was statistically significant ($p<0.05$); there was no significant difference between B and W. Phenolic compounds were considered to play a key role as defense compounds against environmental stresses such as high light, low temperature, pathogen infection, and nutrient deficiency in plants (Lattanzio, 2013). Chalker-Scott et al. (2018) found a positive relationship between the increase of light intensity and the amount of phenolic substance. In the current study, it was found that the amount of TSP generally increased during storage in all treatments, and also the TSP content increased by 56% in the R treatment according to the initial value and was followed by B (36%), C (30%), G (24%), and W (12%), respectively. On the other hand, it could also be stated that blue light is more effective than other treatments in terms of preserving the amount of TSP during storage. In the present study, the increase in TSP content in all treatments is confirmed by the findings of the study conducted by Lattanzio (2013). Also, similar to the present study, the yellow LED (590 nm) treatment was found to increase the total amount of phenolic compounds in tomatoes (Kokalj et al., 2016). It was also found that red LED, ultraviolet (UV) light, and red LED + UV treatments increase the content of phenolic substances during storage in green ripe harvested tomatoes (Panjai et al. 2017).

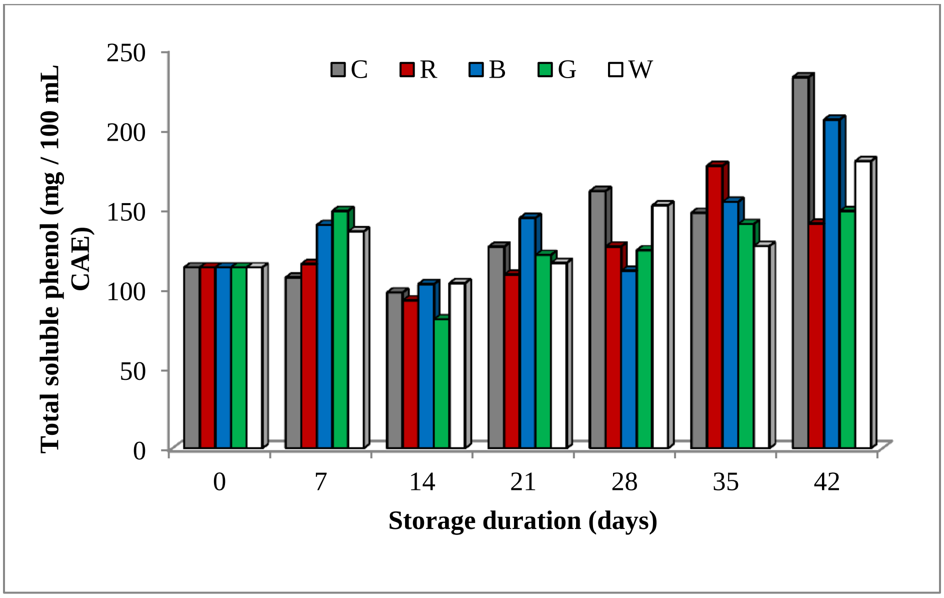

Figure 2. Changes in the total soluble phenol content in tomato fruits treated with LEDs in different colors.

Şekil 2. *Farklı renklerde LED ışık uygulanan domateslerin toplam çözünür fenol miktarındaki değişimler.*

Color values (*L, *a**, *b**, *h*º):** In the study, it found that the overall *L** color value decreased during storage in all treatments (Table 2). However, it was determined that the highest L* color value is in the C treatment (51.85), whereas the lowest is in the G (50.48). The *a** values were varied from 5.19 to 7.02 initially, whereas increased until the 28th days (17.16 - 18.52), and after that decreased (13.75 - 14.74) at the end of the storage (Table 2). b* color values generally decreased in all treatments during storage (Table 2). In the research, however, the lowest *b** color value was measured in C treatment as 15.77, while the highest one was found in the R (16.79). It was detected that the highest *h*º value was in W treatment (51.88) and this was followed by R (50.68), G (49.83), C (49.62), and B (49.51) treatments (Table 2). In general, it was detected that color *L** values have decreased in all treatments as compared to initial values. However, *L** values of tomatoes in C and W treatments higher than G treatment. The increasing of *L** values shows a rise in the brightness of fruits and having a lighter color. As a matter of fact that *a** color values were lower in C and W treatments support this result. Kasım and Kasım (2015) stated that UV-B treatments at two different doses (0.564 kJ / m^2, 1.128 kJ / m^2) to tomatoes which harvested break, pink and red decreased the *L** color values during storage. Similar results were obtained in this study. *a** values increased until the 28th day of storage and then decreased in all treatments. Similar to the present study, it was detected that *a** color value of Belle tomato variety fruits harvested at the semi-red mature stage and stored at 5ºC and 10ºC for 28 days increased at both temperatures and during the storage period (Žnidarčič et al. 2010). Again it stated that *a** color value increased (Kasım and Kasım, 2015) in the fruits of the Tayfun F_1 tomato variety harvested at the pink mature stage and stored for 28 days.

Table 2. L*, a*, b*, h° values in tomato fruits treated with different colors of LED

Çizelge 2. *Farklı LED ışık uygulanan domates meyvelerinin L*, a*, b*, h° değerleri*

	Storage duration (days)	C	R	B	G	W	Time Avg.*
L*	**0**	57.66	55.09	56.41	55.93	56.47	**56.31 a**
	7	54.2	53.9	53.21	53.2	53.16	**53.53 b**
	14	52.33	50.71	51.23	52.39	52.21	**51.78 c**
	21	52.02	50.79	51.12	50.73	51.21	**51.17 c**
	28	50.09	49.89	49.17	47.98	50.37	**49.50 d**
	35	50.4	49.43	48.64	48.94	49.77	**49.44 d**
	42	46.27	45.55	44.75	44.17	43.78	**44.90 e**
	Treatment Avg.*	**51.85 a**	**50.77 b**	**50.65 b**	**50.48 b**	**51.00 b**	
a*	**0**	5.19	6.06	7.02	5.87	5.61	**5.95 e**
	7	11.67	11.52	12.61	12.47	10.67	**11.79 d**
	14	14.73	14.45	15.02	14.74	14.13	**14.61 c**
	21	16.38	17.19	15.9	16.04	16.95	**16.49 ab**
	28	17.16	17.76	17.45	18.52	16.55	**17.49 a**
	35	15.79	16.91	16.4	16.39	15.72	**16.24 b**
	42	14.55	14.74	13.75	13.84	14.09	**14.20 c**
	Treatment Avg.	**13.64 a**	**14.09 a**	**14.02 a**	**13.98 a**	**13.39 a**	
b*	**0**	19.26	18.75	16.42	17.88	19.7	**18.40 a**
	7	17.02	17.29	16.75	17.15	17.35	**17.11 b**
	14	15.83	16.77	16.73	16.35	17.13	**16.56 bc**
	21	16.04	17.98	16.41	15.39	17.17	**16.60bc**
	28	14.92	16.04	15.94	16.51	15.97	**15.88 c**
	35	14.54	17.23	16.98	16.53	15.14	**16.08 c**
	42	12.76	13.49	13.68	13.48	14.94	**13.67 d**
	Treatment Avg.	**15.77 b**	**16.79 a**	**16.13 ab**	**16.18 ab**	**16.77 a**	
h°	**0**	75.03	72.11	66.04	71.85	74.14	**71.83 a**
	7	55.57	56.33	53.01	53.94	58.47	**55.46 b**
	14	47.09	49.27	48.12	47.97	50.56	**48.60 c**
	21	44.44	46.28	45.9	43.82	45.42	**45.17 d**
	28	41.01	42.1	42.41	41.74	43.98	**42.25 e**
	35	42.64	45.66	46.01	45.36	43.84	**44.70 d**
	42	41.53	42.99	45.04	44.13	46.78	**44.09 de**
	Treatment Avg.	**49.62 b**	**50.68 ab**	**49.51 b**	**49.83 b**	**51.88 a**	

*C: Control, R: Red LED, B: Blue LED, G: Green LED, W: White LED * The different letters in line represent the significant differences among the storage duration at the level of $p<0.05$, ** The different letters in column represent the significant differences among the treatments at the level of $p<0.05$.*

In this study, it was also found that the color *a** values of tomatoes stored under red and blue LED light was higher than other treatments. Liu et al. (2009) found that the *a** and *b** values of tomatoes harvested at breaking the mature stage were slightly but significantly affected by daily pulsed UV-C, red light, or sunlight treatments during 21 days. So, a similar trend to the previous study results was also observed in the present study in which color *a** values of tomatoes were affected by light treatments, particularly red and blue LEDs. Color *b** of tomatoes decreased in all treatments during storage, and a similar result was detected from hue (ho) values. However, it had found that the color *h°* and *b** values of tomatoes in R and W treatments are higher than the other applications. Thus, it is thought that the forming of red color delayed by these treatments. Abiotic stress conditions are effective in the color formation of fruits. Light has also a significant regulatory role in the ripening process. Lavdas (2016) found that blue light accelerated softening and ethylene synthesis of tomato fruits, and also Zhang et al. (2020) stated that ripening and also the color transition of wild-type tomato fruit grown under supplementary red light accelerated, and also they declared that it was due to associated with the increased expressions of genes encoding ripening-related regulators and ethylene biosynthesis. Furthermore, Huang et al. (2018) found that the ripening of bananas was accelerated by blue light followed by red and green, and observed that under the irradiation of LED lights, faster peel de-greening and flesh softening, and increased ethylene production and respiration rate during storage. So in the present study, it is thought that the blue and green light may be more accelerated production of ethylene than the red and white light, and therefore the red color formation is high in tomatoes under blue and green light.

Total soluble solid (TSS) content (%): In the study, the TSS content, which increased until the 7th day of storage in all treatments except the B, decreased in all applications from this period to the 28th day of the storage, except R. Also, the amount of TSS, which was 4.7 at the beginning and varied between 4.1 and 4.5 at the end of the storage period, but there was no statistically significant difference between the treatments ($p>0.05$) (Table 3). TSS expresses sugar and minerals are present in fruits and vegetables, and generally increased during ripening and storage. During maturation, the cell wall polysaccharides, hemicellulose, and pectins are broken down and provide the release of oligosaccharides called simple sugars (Dumvilli and Fry, 2000). Azzolini (2005), stated that the amount of TSS depends on the maturation stage, and in general, the content increases during the maturation due to the hydrolysis of polysaccharides for respiratory protection. In the study, it found that the amount of TSS of tomatoes increased to the 7th day of storage, and this increase continued to the 21st day for R, and then decreased in all treatments until the end of the storage period. Islam et al. (2012) determined that the TSS content of tomatoes rose from 4.20% to 5.00% after 7 days at room temperature, whereas from 4.10% to 4.90% during 17 days of storage in the low energy cooling chamber. In the present study, the amount of TSS of tomatoes increased in G and B until the 14th day and in R with the 28th day as similar to findings by Islam et al. (2012), and then decreased until the end of the storage period. It was thought that this result is due to the harvesting of the tomatoes used in the study during the breaking stage, and the amount of TSS increased primarily due to ripening and then decreased as a result of aging and respiration. Also, Lei et al. (2016) stated that continuously red and blue LED illumination at $4^{o}C$ temperature during 20 days caused the highest TSS content of cherry tomatoes, which harvested the breaker stage at the 10th day of storage. Lei et al. (2016) also declared that this treatment significantly delayed the decreasing of the TSS content of cherry tomatoes. The results of this study, in which R treatment increased the TSS content of tomatoes until the 28th day of storage, were found similar to the findings by Lei et al. (2016).

Fructose, glucose and sucrose content (%): The fructose content of tomatoes except for R treatment first increased to the 7th day of storage, then decreased (14th day), after that increased again on the day of 21 (Table 3). The highest fructose content, however, was found in control (0.229%), followed by B (0.228%), G (0.221%), R (0.218%) and W (0.216) treatments. Also, there were insignificant differences among C, B, and G treatments, whereas significant differences between these treatments with R and W ($p<0.05$). In the study, it was determined that tomatoes in C (0.224%) have the highest glucose content and are followed by B (0.219%), G (0.214%), R (0.213%), and W (0.208%). The sucrose content of tomatoes in all treatments was 0.51%, and it showed an increase at the day of seven except for B and ranged 0.052-0.055% (Table 3). Then, it decreased until at the end of storage and reached the initial level. However, the highest sucrose content was found in C (0.0510%), whereas the lowest value was in B (0.0503%), but the differences among these two treatments were not statistically significant ($p>0.05$, Table 3). The fructose content of tomatoes fluctuated until the 21st day of storage, but generally the fructose content of tomatoes in C was higher than the other treatments. Therefore, it could be stated that the LED light treatments caused a decrease in fructose content. However, it has been thought that the W amongst the LED lights has shown the highest impact because the fructose content of tomatoes in W was the lowest. Also, similar results were supported by the glucose content of tomatoes, where the highest glucose in C, whereas the lowest in white LED treatment.

Table 3. TA (%), TSS (%), glucose (%), fructose (%) and sucrose (%) contents of tomato fruits treated with different LED light

Çizelge 3. *Farklı LED ışık uygulanan domates meyvelerinin TA (%), TSS (%), glikoz (%), fruktoz (%) ve sakkaroz (%) miktarları*

	Storage duration (days)	C	R	B	G	W	Average
TA (%)	**0**	0.3	0.3	0.3	0.3	0.3	**0.30 b**
	7	0.43	0.37	0.35	0.33	0.37	**0.37 a**
	14	0.33	0.28	0.29	0.27	0.26	**0.29 b**
	21	0.29	0.32	0.33	0.29	0.27	**0.30 b**
	28	0.25	0.31	0.32	0.3	0.2	**0.29 b**
	35	0.26	0.25	0.34	0.27	0.28	**0.28 b**
	42	0.27	0.24	0.26	0.25	0.38	**0.28 b**
	Average	**0.30 a**	**0.30a**	**0.31 a**	**0.29 a**	**0.30 a**	
TSS (%)	**0**	4.7	4.7	4.7	4.7	4.7	**4.7 ab**
	7	5.1	5	4.7	5.1	4.9	**4.9 a**
	14	4.5	4.8	4.8	4.9	4.5	**4.7 ab**
	21	4.6	5	4	4.6	4.5	**4.7 ab**
	28	4.4	5.2	4.5	4.3	4.6	**4.6 b**
	35	3.9	4.1	4	3.8	4	**4.0 d**
	42	4.4	4.4	4.1	4.2	4.5	**4.3 c**
	Average	**4.5 a**	**4.7 a**	**4.5 a**	**4.5 a**	**4.5 a**	
Fructose (%)	**0**	0.242	0.242	0.242	0.242	0.242	**0.242 a**
	7	0.253	0.217	0.26	0.257	0.26	**0.250 a**
	14	0.226	0.215	0.217	0.201	0.202	**0.212 c**
	21	0.251	0.232	0.233	0.217	0.202	**0.227 b**
	28	0.22	0.229	0.221	0.217	0.208	**0.219 bc**
	35	0.211	0.214	0.241	0.21	0.203	**0.216 c**
	42	0.197	0.178	0.18	0.201	0.194	**0.190 d**
	Average	**0.229 a**	**0.218 b**	**0.228 a**	**0.221 ab**	**0.216 b**	
Glucose (%)	**0**	0.225	0.225	0.225	0.225	0.225	**0.225 b**
	7	0.246	0.202	0.243	0.233	0.255	**0.236 a**
	14	0.22	0.208	0.212	0.189	0.186	**0.203 d**
	21	0.243	0.229	0.225	0.211	0.196	**0.221 bc**
	28	0.211	0.222	0.213	0.214	0.202	**0.212 cd**
	35	0.219	0.22	0.237	0.224	0.207	**0.221 bc**
	42	0.203	0.184	0.178	0.2	0.189	**0.191 e**
	Average	**0.224 a**	**0.213 bc**	**0.219 ab**	**0.214 bc**	**0.208 c**	
Sucrose (%)	**0**	0.0508	0. 0508	0. 0508	0. 0508	0. 0508	**0.0508 bc**
	7	0.0538	0.0520	0.0514	0.0552	0.0530	**0.0531 a**
	14	0.0518	0.0500	0.0494	0.0495	0.0499	**0.0501 cd**
	21	0.0496	0.0498	0.0493	0.0494	0.0497	**0. 0496 d**
	28	0.0499	0. 0495	0. 0497	0. 0496	0. 0496	**0. 0497 d**
	35	0. 0503	0.0510	0. 0506	0. 0502	0. 0501	**0. 0504 bcd**
	42	0.0506	0.0506	0.0511	0.0513	0.0517	**0. 0511 b**
	Average	**0.0510 a**	**0.0505 ab**	**0.0503 b**	**0.0509 ab**	**0.0507 ab**	

*C: Control, R: Red LED, B: Blue LED, G: Green LED, W: White LED *The different letters in line represent the significant differences among the storage duration at the level of p<0.05, **The different letters in column represent the significant differences among the treatments at the level of p<0.05.*

In the present study, the amount of fructose and glucose decrease during storage and fall below the initial value, whereas sucrose content was stabile and close to the initial value in all applications. Similarly to the glucose and fructose, it was detected that the sucrose content of tomatoes in C higher than the others, while the lowest one in blue LED treatment. Similarly to the glucose and fructose, it was detected that the sucrose content of tomatoes in the C treatment higher than the others, whereas the lowest value was in the blue LED light. Although some studies found that the effect of LED light on the sugar content of tomatoes, which is growing under the LED light (Lavdas, 2016; Li et al. 2017; Fanwoua, 2019; Ntgkas et al (2019); Zhang et al. 2020), there is more limited study on sugar metabolism of tomatoes under LED lighting during the storage. It was found one of them (Lei et al. 2016) that the accumulation of reducing sugar and total soluble solids in cherry tomatoes could be decreased by red and blue RED light irradiation during the early stage of storage. The authors also stated that the highest reducing sugar and total soluble sugar content calculated on the 10th day and then gradually decreased between the 10th and the 20th days, also it was higher in the tomatoes irradiated by LED red and blue weak light than that in the control during the whole storage. Similarly, it has been detected that the fructose and glucose contents of tomatoes in all treatment groups except for red light increased during the first seven days and then decreased until at the end of storage in the present study. The sucrose content of tomatoes, however, increased in all treatments and then decreased. Furthermore, the average of fructose, glucose, and sucrose showed that the highest values were in control group, and therefore it could be said that the different LED light treatments do not affect sugar content.

Titratable acidity (TA, %): Although the titration acidity of tomato fruits increased 43% in the control group, 23% in red and white LED applications, 17% in blue LED applications, and 10% in green LED applications on the seventh day of storage, it decreased again after this period and dropped below the initial value at the end of the storage period (Table 3). However, since there are no significant differences between applications in terms of titration acidity, it was thought that LED lighting applications did not affect the titration acidity of tomato fruits. Nájera et al. (2018) stated that the R: FR ratio affects titratable acidity of tomatoes and found that the highest R: FR ratio caused in tomatoes higher titratable acidity than those exposed to lower R: FR ratios. Adversely in the present study, it has been found that the LED treatments, regardless of color, did not cause an increase in titratable acidity of tomatoes, the TA content of tomatoes in all treatments decreased during storage. Although not statistically significant, the highest decrease occurred in tomatoes in G application, while the least decrease occurred in B application. This shows that the B application slows down the ripening of fruits compared to other applications. Furthermore, this result also could be originated from light density differences between these two studies.

Fruit firmness (N): It observed that the flesh firmness of tomato fruits to which different LED was applied increased in the first week in all applications but decreased continuously in the following weeks (Figure 3). On the other hand, in the study, the highest fruit firmness value was obtained in the R application (21.03 N), and followed by W (20.87 N), B (20.24 N), G (19.35 N), and C (18.86 N). Also, the difference between C and LED treatments were found to be statistically significant at the $p < 0.05$ level. In the study, it was found that the most decreasing fruit firmness occurred in the control group, and it retained higher in LED applied samples. Therefore, it was observed that LED lighting treatments are effective in preserving fruit firmness. In a study, it was detected that blue light treatment was more effective in preserving firmness in green-ripe tomatoes treated with blue (440-450 nm) and red light (650-660 nm) during 7 days. Therefore, researchers have stated that the blue LED light could be used to delay the ripening of tomatoes, thus increasing their commercial value (Gupta, 2017). This result supports the findings obtained in this study .

Electrolyte leakage (EL, %): Accordingly, in this study, although the amount of EL generally increases during the storage period in all applications (Figure 4), the highest EL content was measured in tomato fruits in the control group (60.76%) and followed by G (60.19%), W (59.14%), R (58.31%) and B (56.29%) treatments. However, it was determined that the difference between the applications in terms of electrolyte leakage was not statistically significant ($p > 0.05$). Senescence or abiotic stress conditions cause an increase in the amount of EL of fruits and vegetables. In the study, in general, EL increased in all treatments during storage. On the other hand, it has been determined that the EL content of fruits under all LED light is lower than the control until the 21st day of storage and during the storage period in R and B LED applications. Therefore, it has been concluded that these two LED light applications reduce the electrolyte leakage by delaying the aging of fruits.

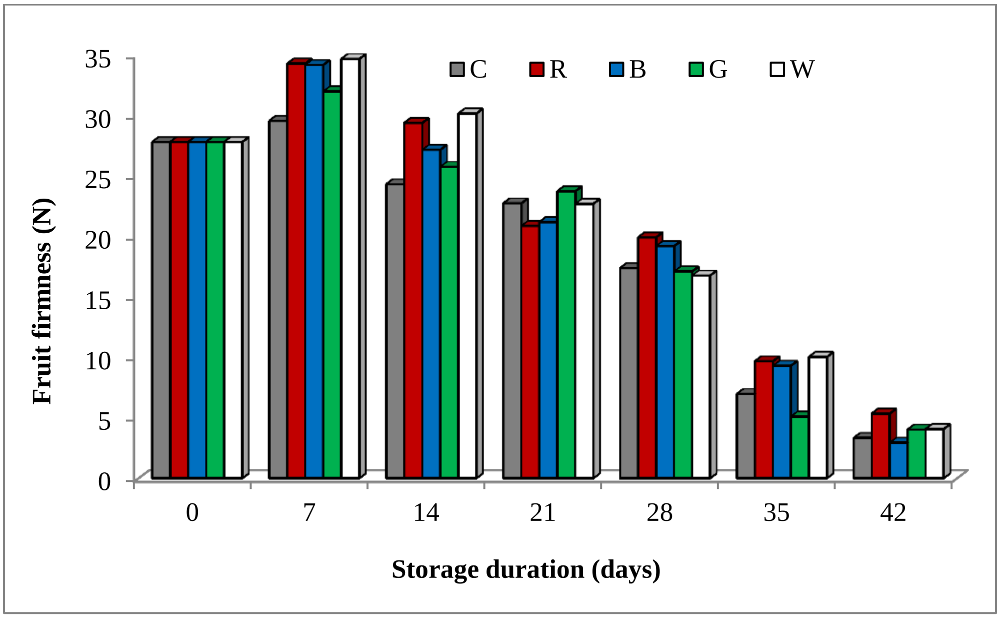

Figure 3. The changes in fruit firmness value of tomatoes treated with different color LED light.

Şekil 3. *Farklı renklerde LED ışık uygulanan domateslerin meyve eti sertliğindeki değişimler.*

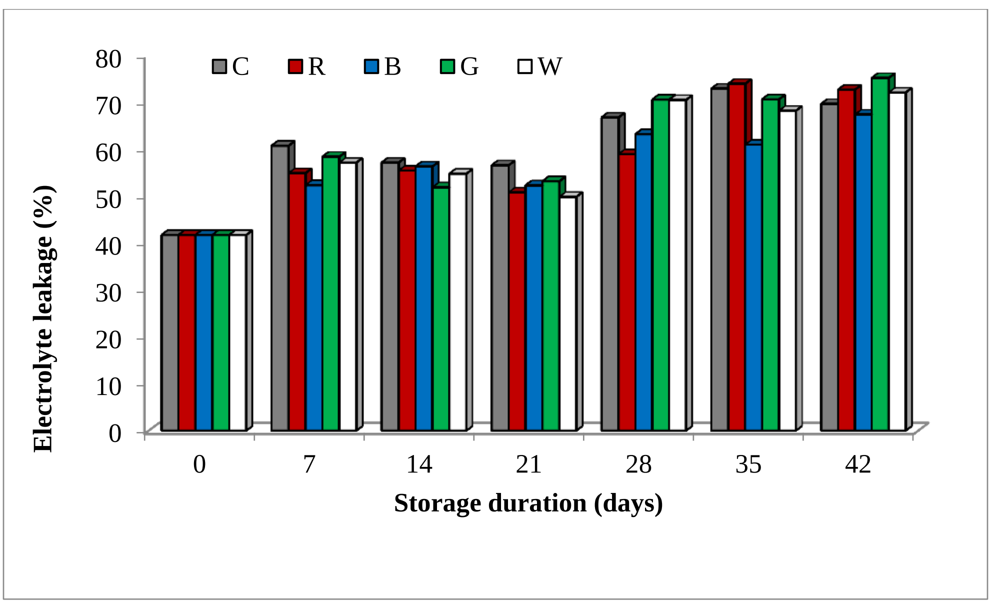

Figure 4. The changes in electrolyte leakage value of tomatoes treated with different color LED light.

Şekil 4. *Farklı renklerde LED ışık uygulanmış domateslerde elektrolit sızıntısı değişimleri.*

Weight loss (%): The weight loss of tomatoes generally increased in all treatments during storage, whereas the most weight loss occurred on the 42nd day. During this period, it was determined that the highest weight loss occurred in the control group with 3.33%, whereas the least weight loss was in the R application with 1.56% (Figure 5). Affandi et al. (2020) stated that the additional far-red LED light treatment during cultivation reduced the weight loss of tomatoes harvested in the mature green stage. Adversely, in the current study, the postharvest red LED light treatment did not reduce the weight loss of tomatoes. But, the weight loss of tomatoes was lower in W treatment compared to the control group and other LED treatment. So, it could be stated that the W LED treatment can be used to reduce the weight loss of tomatoes after harvest.

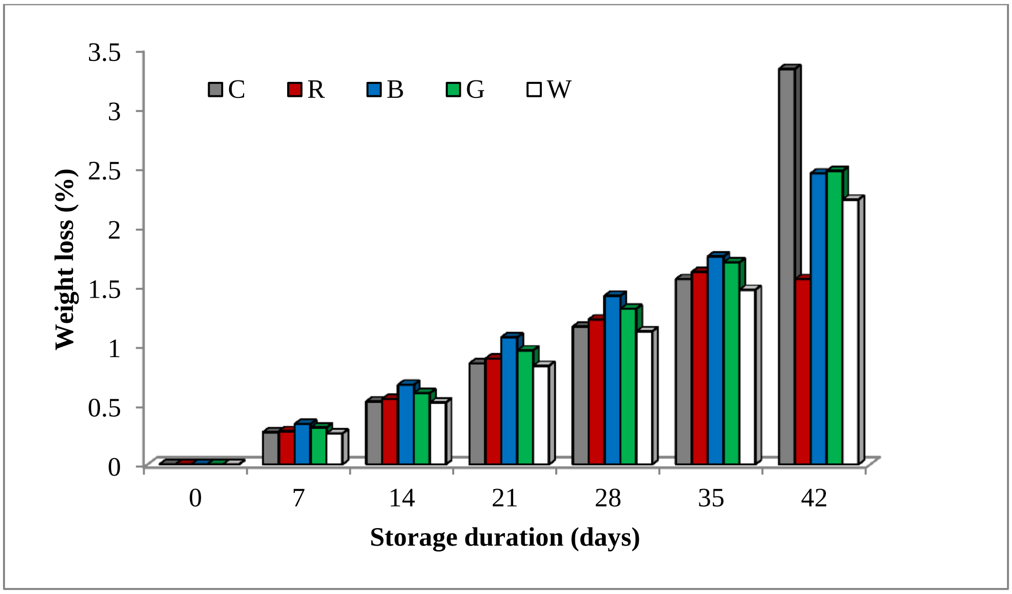

Figure 5. The changes in weight loss of tomato fruits treated with different color LED light.

Şekil 5. *Farklı renklerde LED ışık uygulanan domates meyvelerinin ağırlık kayıplarındaki değişimler.*

Decay rate (%): In the study, no decay occurred in any treatment group during the first 14 days of storage. However, the decay started on the 21st day, in R, B, and W treatments (Figure 6), and then occurred in all treatments. But the highest decay rate was calculated in W with 0.41% ($p<0.05$), and followed by G, C, R, and B treatments with 0.38%, 0.35%, 0.28%, and 0.28% respectively. Therefore, it could be said that especially blue and red LED light was effective in reducing decay. Lei et al. (2016) found that the quality of cherry tomato fruits harvested at the green-mature (breaking stage) stage and applied continuous red and blue LED light for 20 days at 4°C, was better preserved than the control group. The researchers also found that the fruits in the control group softened severely, and quality losses occurred in the form of distinct black spots on the skin and fungal rot spots. Similarly to these findings, it was found that the decay rate of tomatoes treated with blue and red light lower than the control group. It has been determined by studies that LED lights to provide surface disinfection in different products. Accordingly, the storage time of the product can be extended by reducing the number of microorganisms on the surface of the products with LED light applications. For example, in Satsuma mandarins (*Citrus unshiu* Marc.*)* inoculated with *Penicillium italicum*, application of blue LED light (465 nm, 80µmol / m^2s) was determined to have an antifungal effect against blue mold (Yamaga et al. 2015).

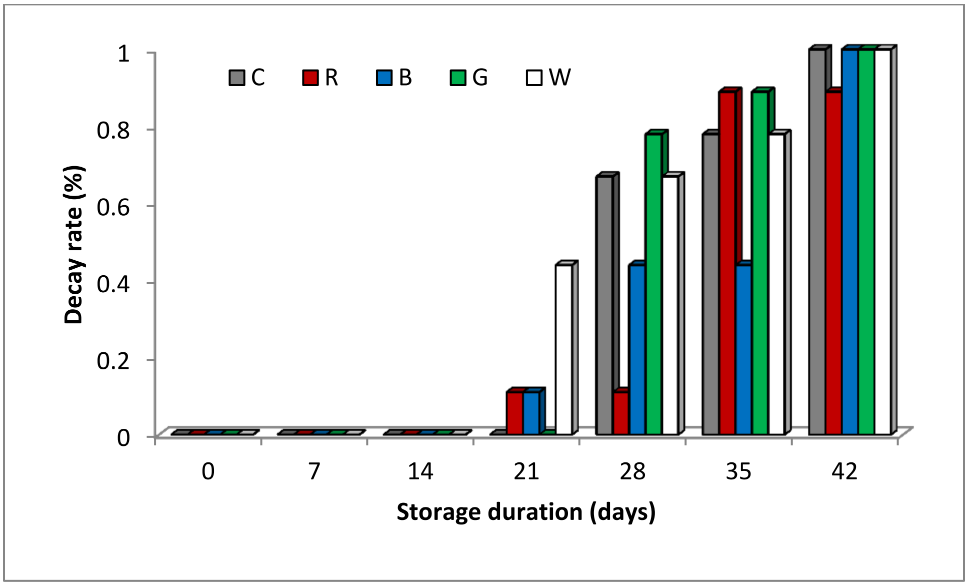

Figure 6. The changes in decay rate of tomatoes treated with different color LED light.

Şekil 6. *Farklı LED ışık uygulanan domateslerin çürüme oranlarındaki değişimler.*

CONCLUSIONS

In this study, the effects of LED lighting in different colors (red, blue, green, and white) on the quality of Zahide F_1 tomato fruits during storage were tried to be determined. When all results are evaluated together, it was concluded that the blue LED treatment preserves the general quality of tomatoes harvested during the breaking stage better than other applications during the maturation in the storage. It was observed that blue and red light are particularly effective in reducing decay. Also, the marketable quality of tomatoes in these two groups, which maintained quality until 35 days of storage, was found higher than the others. Therefore, in future studies, it may be suggested to study other treatments that can be used with red and blue light in terms of preserving the quality of tomato fruits.

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