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The effect of white and red LED lights on coloring and antioxidant capacity of Japanese persimmon at postharvest stage

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ABSTRACT

Purpose: One of the most important subtropical fruits in Iran is Japanese persimmon. Persimmon is a climacteric fruit and continues to ripening after the harvest. One of the main quality components in persimmon fruit is its appearance due to the presence of different carotenoid pigments. Persimmon has also high antioxidant capacity. The use of LED lights is one of the most important commercial techniques to increase the quality and postharvest life of the fruits. In the present study, the effect of LED lights on the coloring and antioxidant capacity of persimmon fruit was studied. **Research method:** The Karaj genotype of persimmon was harvested at commercial stage and exposed to white and red LED lights (at intensity of 40-60 candle/W) up to 21 days at 10°C and 80% RH, as the control fruit was stored at dark conditions. **Findings:** The results showed that the samples of red LED light had higher color index and lower hue° and L * values as compared to control or white LED light samples. Therefore, the red light induced the coloring in persimmon fruit, but the white light did not show such an effect. Also, both white and red LED lights have resulted in better preservation and increased antioxidant capacity in persimmon fruit as compared to control. **Research limitations:** No limitations were encountered. **Originality/Value:** based on the results of this experiment, LED lights are effective treatments in maintaining and increasing the quality of Japanese persimmon at the postharvest stage, and have potential to further investigation and commercialization.

INTRODUCTION

Japanese or oriental persimmon (*Diospyros kaki* Thunb) is the most famous species from the Ebenacea family (Guan et al., 2020). In recent years, the cultivation of persimmon has been developed in Iran and it is being produced and consumed considerably, but useful research has not been conducted in this regard (Khademi et al., 2022). Most persimmons in Iran are astringent type, but the astringency removal treatments are not common in Iran and therefore, the persimmon is harvested at over ripe stage in order to decrease the astringent taste; as a consequence, the fruits lose their high quality with low storability and are not popular in the markets (Khademi et al., 2010).

Persimmons have high antioxidant capacity due to carotenoid, phenolic and ascorbic acid compounds and can be effective in avoiding cardiovascular diseases (Ozen et al., 2004). One of the significant qualitative properties of Japanese persimmon is the beautiful color resulting from lots of carotenoid pigments. Among carotenoids, persimmons are rich of β-crytoxanthin, β-carotene, lutein, zeaxanthin and lycopene, that β-carotene and β-crytoxanthin are provitamin A, although 31 specific carotenoids were detected in persimmon cultivars. The carotenoid content is strongly affected by cultivar, ripening stage, and processing method. In persimmon, the color varies in different cultivars from yellow, and orange to deep red, which is due to the differences between the compositions and contents of carotenoids in the different persimmon cultivars; however, researchers demonstrated that β-cryptoxanthin was the most abundant carotenoids in most persimmon cultivars (Plaza et al., 2012; Zhou et al., 2011).

Plants react to a wide range of lights ranges from ultraviolet to infrared. Sunlight is the main source of light in terms of photosynthesis and physiological processes in plants (Taiz & Zeiger, 2010). However, LED lights are a modern technology, which are of lots of useful applications in food industry and agriculture. LEDs are the members of the family diodes. When in diodes, the electricity passes, the energy is changed in to the light. LEDs formerly could produce red, blue and green lights, which has led to the limitations in use, but recently, LED with white light has been produced, which can produce the white light with a halo of blue color. Now, LEDs have more advantages as compared to the other light resources involving; production of specific wavelengths, production of monochrome light, production of less heat, high durability or high useful life, low production expenses, low consumption of energy, production of cold light, small size, safety, regulation of light intensity and quality (Singh et al., 2015; Yan et al., 2020). Nowadays, LED lights have been converted to an accessible, attractive and economic technology in the field of postharvest of horticultural products, so that the application of LED light is one of important strategies for the increased postharvest life of fruits and vegetables as well as the improved coloring (Barta et al., 1992; Cho et al., 2008).

In the studies conducted on the citrus (Ma et al., 2012), tomato (Nájera et al., 2018; Liu et al., 2009), cherry tomatoes (Ngcobo et al., 2021) and bell peppers (Martínez-Zamora et al., 2021), it has been shown that the LED light treatment has led to the increased carotenoids and fruits color. In fact, LED lights play a role in the evolution of fruits color after the harvest because they affect the metabolism of pathways involved in pigments biosynthesis. The properties of light spectrum influence the synthesized pigments, which play a determining role in the quality of products (Nájera et al., 2018).

On the other hand, LED lights are effective treatments in inhibiting senescence and maintaining the product quality during storage or shelf life by the improved antioxidant properties (Maroga et al., 2019; Song et al., 2020). Exposure to LED lights induced different antioxidant systems in the plant cells such as phenylpropanoid or carotenogenesis pathways via the related enzymes activations. The positive effect of LED lights on increasing the functional bioactive compounds has been shown in bell peppers (Martínez-Zamora et al., 2021) and cherry tomatoes (Ngcobo et al., 2021), and in fact, light quality, light intensity, and irradiation duration affect the effect of light treatment (Song et al., 2020). Since the senescence is an oxidative stress, the improved antioxidant compounds can delay the senescence (Maroga et al., 2019).

LED lights technology may affect the harvested fruits and vegetables considerably. However, to determine the effect of LED light mechanism on the postharvest quality of fresh products, more research is required. So far, no reports have been published in the field of LED lights impact on the coloring and qualitative properties of persimmon; in the current study, the impact of red and white LED lights has been investigated on the color properties and antioxidant activities in the Japanese persimmon at postharvest stage.

MATERIALS AND METHODS

The persimmon fruit with common name of "Karaj" genotype at firm and orange color stage was harvested from an orchard near to Karaj city and immediately transported to the postharvest laboratory of Department of Horticulture, Shahed University (Khademi et al., 2012). The intact and defect-free fruits were selected and divided into three groups, each group containing 60 fruits, the first group was exposed to the darkness as control, the second group was exposed to the red LED light treatment (660nm, 40-50 candle/W), and the third group was exposed to white LED light treatment (449nm, 50-60 candle/W). For light treatments the apparatuses were made from a steel frame in the dimensions of 1 m length × 0.5 m width × 0.5 height, and LED lamps for each treatment were mounted on each frame, and distance between the fruits and lamps was set at 20 cm. The surroundings of the apparatuses were covered with black polyethylene to prevent lights from the outside (Arslan et al., 2021). The fruits were continuously subjected to lights treatments at 10°C and RH above than 80% for up to 21 days, inside the cold chamber. At 0 (harvest time), 7, 14 and 21 days of the storage, 15 fruits from each treatment were taken out and evaluated.

The firmness (penetration test) of the fruits was evaluated using a hand penetrometer (model VBR80, Italy) with 8-mm plunger at 3 equatorial points after removing peel and the result was expressed as N. The color parameter of L^*, a^* and b^* was determined at various points of each fruit using a colorimeter (model TES-300, Taiwan) and hue angle and color index was calculated by the following equations (1 and 2) (Khademi et al., 2013).

$$Hue^\circ = \tan^{-1}(b^*/a^*) \qquad (1)$$

$$\text{Color Index} = (1000a/Lb) \qquad (2)$$

For the determination of antioxidant capacity, 0.2 gr of frozen sample was homogenized in 3 mL of 80% methanol and the homogenate was centrifuged at 8000 g for 10 min at 4°C. To 250 µL of resultant supernatant, 250 µL of 1mM DPPH (1, 1-diphenyl-2-picryl hydrazyl) was added and after 30 min incubation at room temperature in dark conditions, the absorbance (ABS) of the resulting solution was spectrophotometrically measured at 515 nm and the percentage of reduction in DPPH was calculated based on the following equation (3) (Naser et al., 2018):

$$DPPH\ (\%) = (1-(ABS_{sample}/ABS_{control})) \times 100 \qquad (3)$$

A randomized completely design with three replicates per treatment was used in this experiment. To determine the effects of light treatments and storage time on each dependent variable, a two-way analysis of variance was carried out using SAS software (version 9.3). Mean values of the treatments were compared by Least Significant Difference test (*LSD*, *P*=0.05).

RESULTS

The ANOVA results related to LED lights treatments and storage time (ST) factors and their interaction on Karaj persimmon have been shown in Table 1.

Fruit firmness

Suitable tissue firmness is one of the main quality components in persimmon fruit, therefore, maintaining firmness and preventing softening of the fruit are the most important factors in the postharvest of persimmon (Salvador et al., 2008). In this fruit, softening takes place under the control of ethylene, in which the up-regulated enzymes involved in degradation of cell wall material (Khademi et al., 2014; Nakano et al., 2001).

The result of this study showed that the firmness value of the samples decreased significantly over the time of the experiment. At 7-day of the experiment, the firmness value of persimmons treated with red and white LED lights was significantly higher than that of control samples. However, at 14- and 21-day of the experiment, there was no significant difference between the samples in terms of firmness value (Fig. 1). In similar results on the tomato, it has been shown that the treatment with red and white lights was more effective than blue or green lights in preserving the fruit firmness as compared to control at postharvest stage (Arslan et al., 2021). In other study, it was shown that tomatoes exposed to higher red/far red light ratio had increased firmness value more than tomatoes exposed to lower red/far red light ratio (Nájera et al., 2018). However, in this study, LED lights were only effective in preservation of fruit firmness in the first week of the study; since persimmon is very sensitive to softening during the postharvest conditions; no positive effect of LED lights was observed in the continuation of the experiment (Khademi et al., 2014).

Table 1. Statistical analysis of parameters studied: LED lights treatments and storage time (ST) and their interaction for 'Karaj' persimmon.

Treatment	Firmness	L*	Color index	Hue angle	Antioxidant capacity
LED lights	ns	**	**	**	*
ST	**	**	**	**	*
LED × ST	*	**	**	*	ns

*, ** and ns represent significance at the 0.05 and 0.01 levels and non-significance respectively.

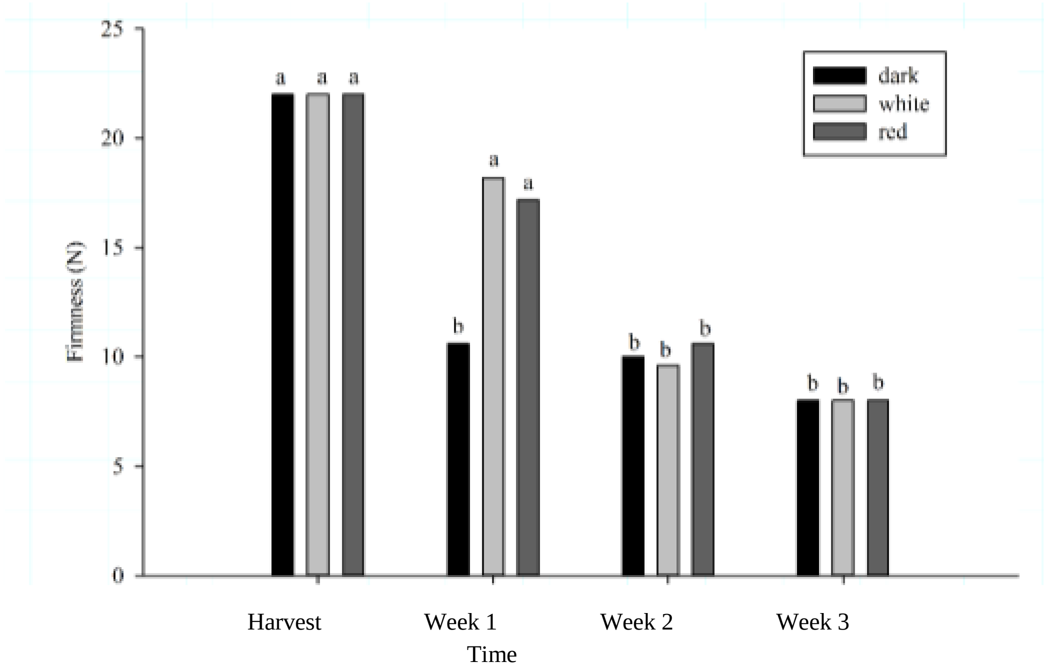

Fig. 1. Firmness value of 'Karaj' persimmon exposed to red and white LED lights for 21 days at 10 °C. Means with the same letter are not significantly different at 5% level of the *LSD* test.

Color properties

Persimmon fruit is a rich source of carotenoids, and a lot of changes occur in the amount of carotenoids during the growth and development in this fruit. The highest amount of carotenoid accumulation occurs at full ripening stage in persimmon fruit, which is specified by red-orange color in Karaj persimmon (Naser et al., 2018).

The results showed that the L* value of all samples decreased over the time of the experiment. At 7-day of the experiment, no significant difference was observed between the red light and control samples in L* value, but the white light samples had a higher L* value than control at this time. A similar trend was observed at 14-day of the experiment, however, at the end of the experiment, the samples treated with red LED light had significantly lower L* value than other samples, while no significant difference was observed between the white light and control samples in terms of L* value. In general terms, red light decreased the L* value of persimmon compared to the control in this study, but white light did not show such an effect (Fig. 2).

The color index of all samples significantly increased over the time of the experiment. Based on the results, no significant difference was observed between the samples in terms of color index at 7th day of the experiment. At 14th day of study time, no significant difference was observed between the red light and control samples in terms of color index, but at this time, the lowest color index was detected in white light samples. At 21st day of study time, red light samples had higher color index than others, while no significant difference was observed between the white light and control samples in terms of color index (Fig. 3). In general, red light increased the color index of persimmon fruit in this study, but white light did not show such an effect.

The Hue angle of all samples decreased over the time of the experiment. The results also showed that at 7- and 14- day of the experiment, there was no significant difference between the control and white light or red light samples in terms of Hue angle. But, at the end of the experiment, the Hue angle in the red light samples was significantly lower than that of white light or control samples, while no significant difference was observed between the white light and control samples in terms of the Hue angle (Fig. 4). Therefore, in line with the L* and color index results, the Hue angle result showed that red light increased the coloring of persimmon fruit as compared to control at this experiment, but white light did not show such an effect.

In persimmon fruit, coloring and carotenoid accumulation are usually associated with a decrease in the L* and Hue angle values and increase in the color index value (Khademi et al., 2013). In a similar study, Zhou et al. (2011) in comparisons between 46 different persimmon cultivars showed that lower values of L* and hue angle in astringent cultivars reflected the deeper color in them as compared to non-astringent cultivars, which was caused by higher abundance of carotenoids in astringent types.

In this experiment, red LED light increased the coloring of persimmon fruit, but white LED light did not show a similar effect. Consistent with this results, several studies on tomatoes (Liu et al., 2009; Nájera et al., 2018), cherry tomatoes (Ngcobo et al., 2021), mandarins (Ma et al., 2012) and bell peppers (Martínez-Zamora et al., 2021) have demonstrated that irradiation with red LED light increased color formation by inducing the accumulation of carotenoids. Furthermore, Arslan et al. (2021) found that coloring of tomatoes harvested at breaking stage was not affected by white LED light treatment.

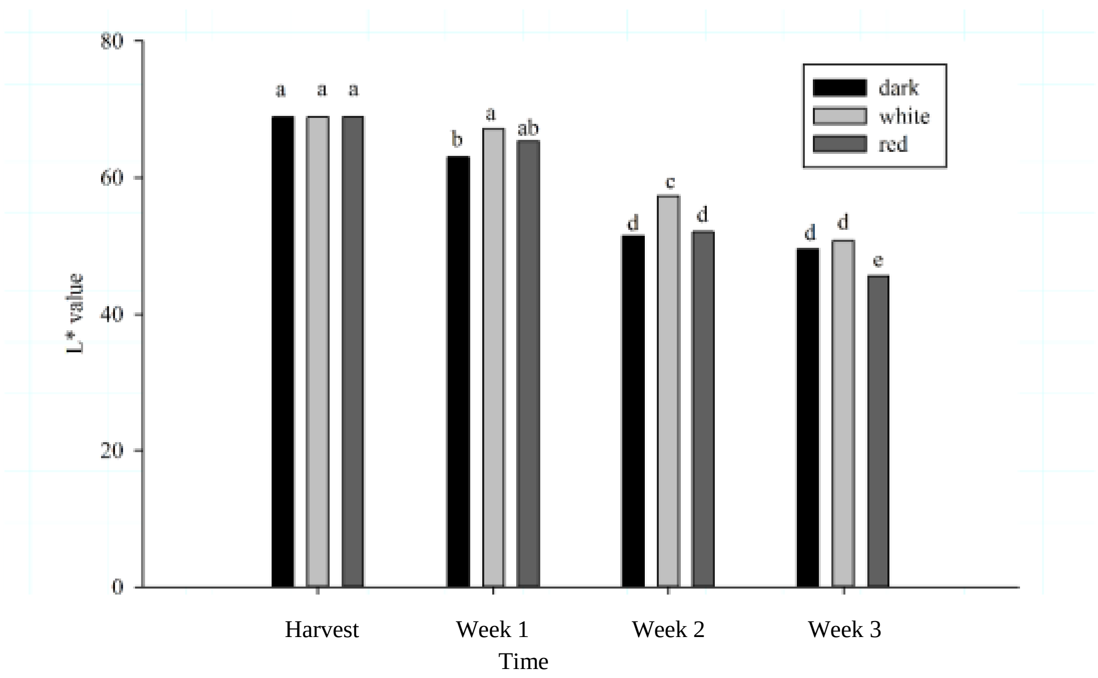

Fig. 2. L* value of 'Karaj' persimmon exposed to red and white LED lights for 21 days at 10 °C. Means with the same letter are not significantly different at 5% level of the *LSD* test.

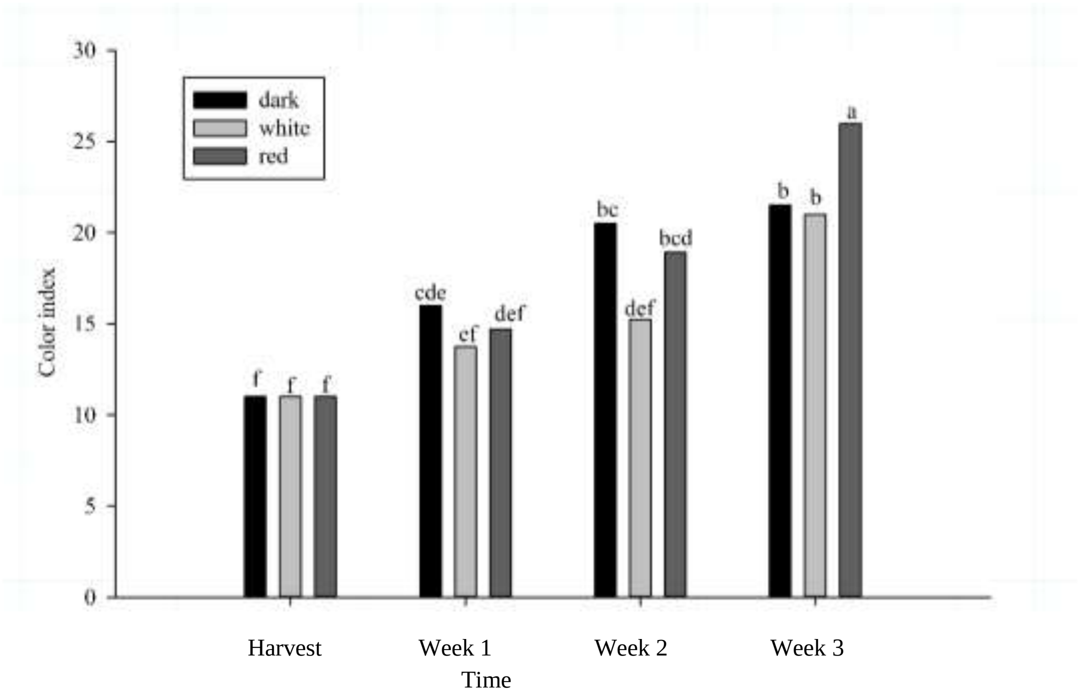

Fig. 3. Color index of 'Karaj' persimmon exposed to red and white LED lights for 21 days at 10 °C. Means with the same letter are not significantly different at 5% level of the *LSD* test.

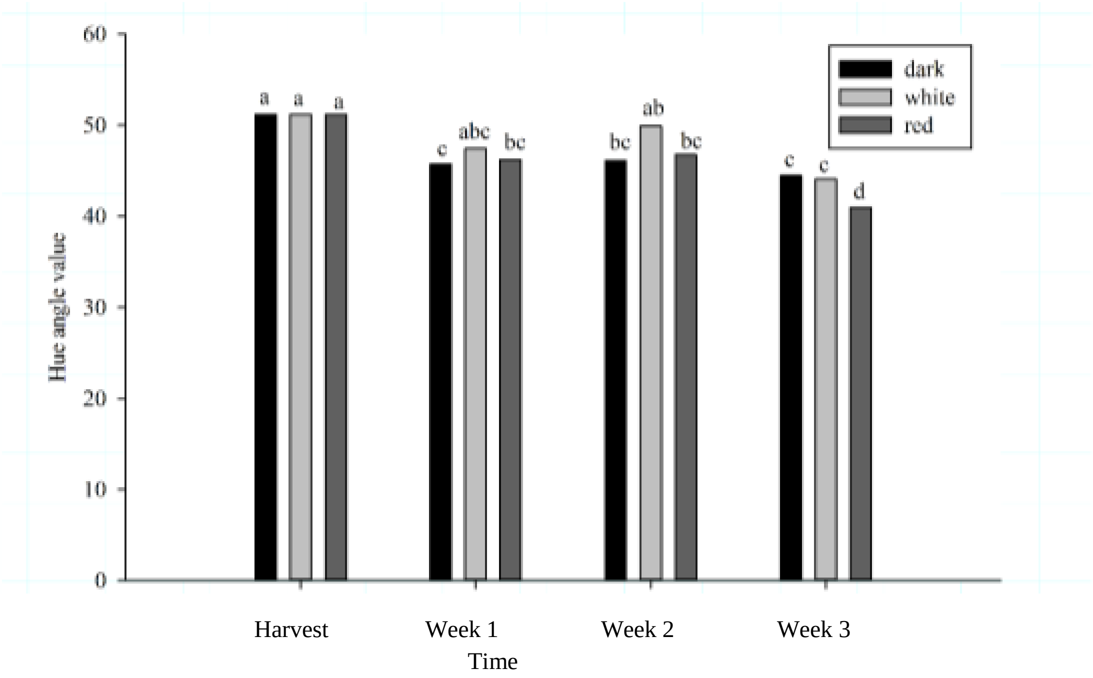

Fig. 4. Hue angle value of 'Karaj' persimmon exposed to red and white LED lights for 21 days at 10 °C. Means with the same letter are not significantly different at 5% level of the *LSD* test.

Liu et al. (2009) in a research on the harvested tomatoes exposed to different lights up to 21 days found that red light treatment had greater effect than sun light on carotenoids contents and coloring in tomatoes. Stimulating effect of red light on the carotenogenesis could be explained by the light-dependent synthesis of certain genes or enzymes involved in the formation of carotenoids such as phytoene synthase. Phytoene synthase is the first enzyme in carotenoids production pathway and increased its expression leading to the enhanced carotenoids production (Martínez-Zamora et al., 2021; Ngcobo et al., 2021).

Antioxidant capacity

The antioxidant capacity of all samples decreased over the time of the experiment (Fig. 5-A). The results also showed that; the antioxidant capacity of LED lights treated samples was higher than control samples, however, there was no significant difference between the red and white lights samples in terms of antioxidant capacity in this experiment (Fig. 5-B).

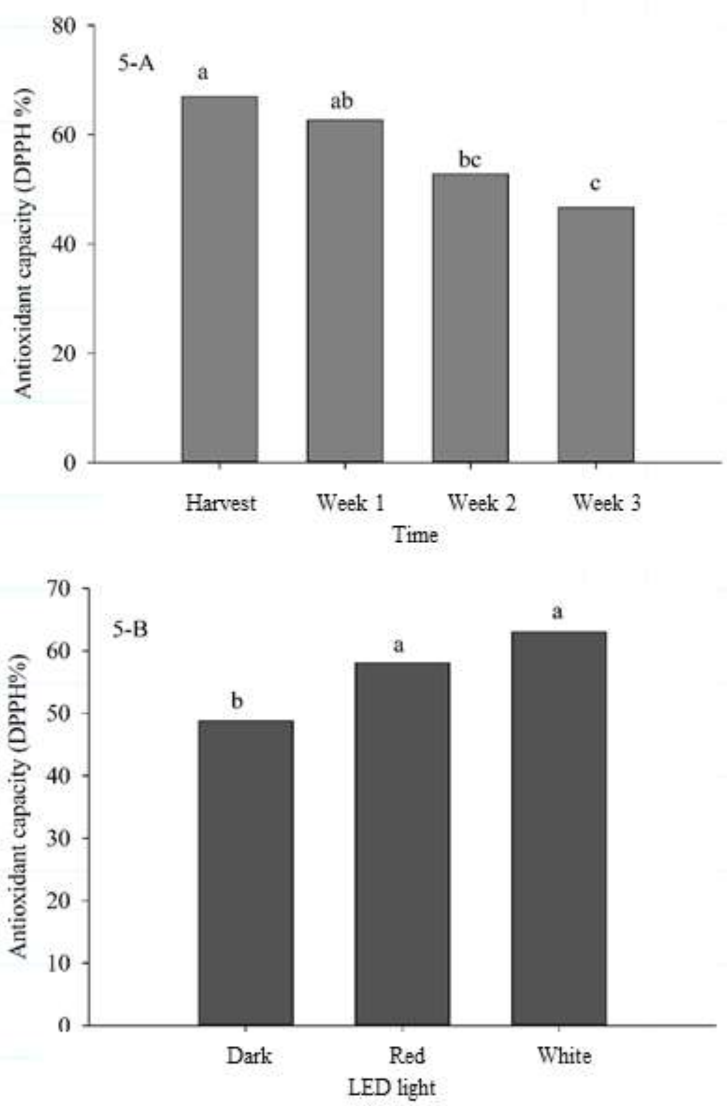

Fig. 5. Effects of studying times (5-A) and LED lights (5-B) on the antioxidant capacity of 'Karaj' persimmon exposed to red and white LED lights for 21 days at 10 °C. Means with the same letter are not significantly different at 5% level of the *LSD* test.

An important part of fruits nutritional value is related to the antioxidant compounds which refer to a group minimizing the oxidative damage to the alive creatures through the reactions with free radicals and reactive oxygen species, which are considerably dangerous to the living cells (Vicente et al., 2005). Persimmon has higher antioxidant capacity than such fruits as apples, blueberries, grapes, tomatoes. Even though, persimmon is regarded as a rich source of dietary fiber, minerals, vitamin A, vitamin C, carotenoids and phenolic components, it is well known that antioxidant capacity of persimmon is significantly correlated with phenolic components. (Li et al., 2011). The antioxidant capacity in persimmon fruit is usually reduced under the storage condition, as observed in control samples (Khademi et al., 2014), but according to the result presented here, this reduction has been alleviated by red and white LED lights. The significant positive effect of LED lights on preserving antioxidant capacity agrees with the results from the investigations on fresh-cut sweet peppers (Maroga et al., 2019), intact bell peppers (Martínez-Zamora et al., 2021), habanero peppers (Pérez-Ambrocio et al., 2018), pak chois (Song et al., 2020), tomatoes (Baenas et al., 2021) and bananas (Huang et al., 2018). Light is an essential factor in biosynthesis of functional compounds, and the quantity and quality of applied light can affect the bioaccumulation of antioxidant compounds (Martínez-Zamora et al., 2021). It has been reported that exposure to LED lights induced the activity of phenylalanine ammonia lyase (PAL), PAL enzymes converts phenylalanine to trans-cinnamic acid in the top of phenylpropanoid pathway and this pathway is responsible for the production of different types of phenolic components (Huang et al., 2018; Maroga et al., 2019) which have been directly related to the antioxidant capacity in persimmon fruit (Li et al., 2011); therefore, increased biosynthesis of phenolic components under red and white LED lights postponed antioxidants depilation in persimmon fruit under the postharvest conditions (Baenas et al., 2021).

CONCLUSION

The research results indicated that the red LED light has had positive impact on the preservation of firmness and antioxidant capacity in persimmon fruits, in addition to the increased color of the fruits. The white LED light has had no significant effect on the color of fruits, but it was effective in preserving the firmness and antioxidant capacity in persimmon. Therefore, LED lights can be considered as the effective treatments for the postharvest of Japanese persimmon fruit, and they require further investigations in order to be commercialized.

Conflict of interest

The authors declare that there is no conflict of interest.

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