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The effect of ultraviolet irradiation (UV-C) on chilling injury of cucumbers during cold storage

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Abstract

Pre-storage exposure of cucumbers (*Cucumis sativus* L. cv. Silor) with ultraviolet irradiation (UV-C) for 3, 5, 10 or 15 min reduced chilling injury until 10 days of storage at 5°C. Electrolyte leakage (EL) of samples treated for 15 min with UV-C was lower than those of the other UV-C treatments and control samples at the 10th day of storage at 5°C. The green colour of UV-C-treated cucumbers was maintained better during storage than that of the control samples, but differences among the treatments were not significant. Weight loss of cucumbers in all UV-C treatments was higher than in control at 5°C, and also weight loss of cucumber at 5°C was higher than at 10°C due to chilling injury. Fruit firmness decreased in all treatments at 5°C, but it remained high in samples at 10°C. The results suggest that UV-C treatments could be a useful non-chemical method to delay chilling injury and deterioration of other quality characteristics of cucumber at 5°C.

Key words: *Cucumis sativus* L., UV-C, electrolyte leakage, chilling injury, storage.

Introduction

Cucumber (*Cucumis sativus* L.), like many warm-season horticultural crops, is injured when exposed to temperatures just above freezing point [1]. So, cucumber is a chilling sensitive commodity and thus should not be stored long term at temperatures below 7-10°C [2-4].

Chilling injury may develop if cucumbers are stored at lower temperatures, as characterized by surface pitting and dark watery patches. This injury is generally followed by an increased tendency to decay, particularly when the temperature is raised. Time is a critical factor with chilling injury, and brief exposures (≤ 2 days) to temperatures below 10°C may cause no damage. The longer the period of exposure and the lower the temperature, the greater the damage associated with chilling injury. However, visual symptoms may not develop until the produce is returned to higher temperatures[5].

Synthetic fungicides have been used wide range to control postharvest decay of produce. Fungicide residues have been found to pose a potential health threat to the consumer and particularly to children [6]. Because of this problem, researchers have attempted to find alternates to chemical pesticides for controlling postharvest diseases of horticultural products [7, 8].

Among the alternate methods for controlling postharvest diseases, ultraviolet-C irradiation (UV-C, 190-280 nm) offers interesting possibilities. UV treatment, especially with radiation at 254 nm, can cause weak stress responses, often associated with the phenomenon of inducible pathogen resistance [9, 10]. This treatment enhances the activity of the phenylalanine ammonia-lyase enzyme [11]. The increases of scoparone and scopoletin in citrus fruit induced by UV-C irradiation may be related to enhanced resistance against pathogens [12]. UV-C irradiation also increases the levels of antioxidants (α-tocopherol, β-carotene and ascorbic acid) in several green vegetables[13]. It has been reported that accumulation of polyamines, putrescine and spermidine, can be considered as an indicator of stresses on fruit including the effects of low temperature storage [14].

The aim of this study was to determine the effectiveness of UV-C treatment in reducing decay and preventing chilling injury while maintaining the quality of cucumbers stored at chilling (5°C) and optimum (10°C) temperature.

Materials and Methods

Plant material and packaging: Cucumbers (*C. sativus* L., cv. Silor) were freshly harvested from a farm in Kocaeli, Türkiye. Fruit uniform in size and free from blemishes were chosen for the experiment. Four cucumbers were placed into polystyrene foam dishes and wrapped in polyethylene stretch film.

Storage conditions and treatments: After packaging cucumbers were divided into five lots for UV-C irradiation. Treatments used were: (1) control (non-treated, K), (2) UV-C irradiation for 3 min, (3) UV-C irradiation for 5 min, (4) UV-C irradiation for 10 min, (5) UV-C irradiation for 15 min. After irradiation, samples were divided in two subplots and stored at 5°C, a chilling temperature, or at 10°C, an optimum storage temperature, for 15 days. During the storage period, changes in quality were determined, and 5 days intervals, 12 fruit from each treatment were evaluated for weight loss, flesh firmness, electrolyte leakage, total soluble solids and visible quality.

UV-C irradiation method: The UV-C irradiation treatment was applied using unfiltered germicidal emitting lamps (TUV 30 W/T8, Philips, Holland). Packaged cucumbers were placed on a wide mesh screen and irradiated with germicidal lamps on upper surfaces at a distance of 30 cm from the screen. UV-C measurements were taken with Spectroline Model DRC-100H

Digital-Radiometer (Spectronics Corporation New York, USA) to determine the spectral irradiance of the bare lamp. The integral value of spectral irradiance for the wavelength range of 250-280 nm was determined as 7166 mW m^{-2}.

Determination of quality attributes: Cucumbers were weighed before storage and 5 days intervals during storage period to calculate percentage of fresh weight loss. For the flesh firmness cucumbers were cut in two portions and flesh firmness was determined at the center of each part of fruit using a firmness tester, Pressure Tester Model with 8 mm plunger. Total soluble solids of juice extracted from four mid section fruit pieces were determined by a hand refractometer at 20°C.

Determination of electrolyte leakage: Electrolyte leakage was measured as fruit discs (5 mm diameter) cut out of the fruit. The discs were washed several times in distilled water and then incubated in distilled water. Conductivity was measured after 2 h of incubation. Total electrolyte conductivity in the discs was measured after they had been frozen and thawed. Electrolyte leakage was calculated as the percentage of the conductivity after 2 h out of total [15].

Colour measurements: The color attributes L*a*b* of two opposite sides of each cucumber in each replicate were measured using a chroma meter (Model CR-400, Conica-Minolta, Osaka, Japan). The first side of the cucumber measured was the upper side, followed by the lower side of packages. The hue angle (h^o) was calculated as $h^o = \tan^{-1}(b/a)$, when a>0 and b>0 or as $h^o = 180^o - \tan^{-1}(b/a)$ when a<0 and b<0 [16].

Experimental design: Experiments were conducted in a completely randomized design with a minimum of four replications per storage treatment per sampling date. Data were calculated as averages ± standard deviations or analysed by ANOVA with calculation of the LSD at $p < 0.05$ (Minitab for Windows).

Results

Electrolyte leakage: The electrolyte leakage (EL) expressed as a percent of total electrolyte leakage was between 9.48 and 12.60% at harvest and had less increase for the first 5 d in storage (Fig. 1). EL rates were after 10 d in storage between 16.14 and 25.27% at 5°C, twice the rate seen at harvest. There were no significant differences among the treatments at the end of the storage but these values were significantly higher than the EL rate of cucumbers stored at 10°C which varied between 9.12 and 12.36%. The rate of electrolyte leakage of both K- and UV-C-treated cucumbers was dependent on the storage temperature. The storage temperature of 5°C severely increased the rate of EL but it was lower in UV-C-treated samples at the 10th day of storage than those of K treatment. Electrolyte leakage increased in all treatments at the end of the storage but it was higher in UV-C-treated cucumbers than that of K, but there were no significant differences among the treatments.

Color changes: The a* value of cucumbers in K increased during the storage period both at 5 and 10°C, but lower changes were observed in cucumbers treated with UV-C and also differences between K and all UV-C treatments were significant (Fig. 2a). However, there were no significant differences among the UV-C treatments. These results correlated with b* values of samples (Fig. 2b). Same trends were obtained by hue angles of cucumbers during the storage (Fig. 2c). Hue angles of cucumbers treated with UV-C increased until 10th day of storage both at 5 and 10°C, and changes of hue angle value of cucumbers were similar to a*

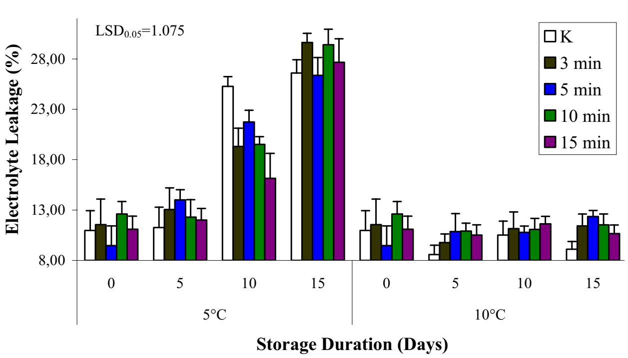

Figure 1. The rate of electrolyte leakage of cucumbers treated with different doses of UV-C and control during storage. Each bar is the mean of four replication ± SE.

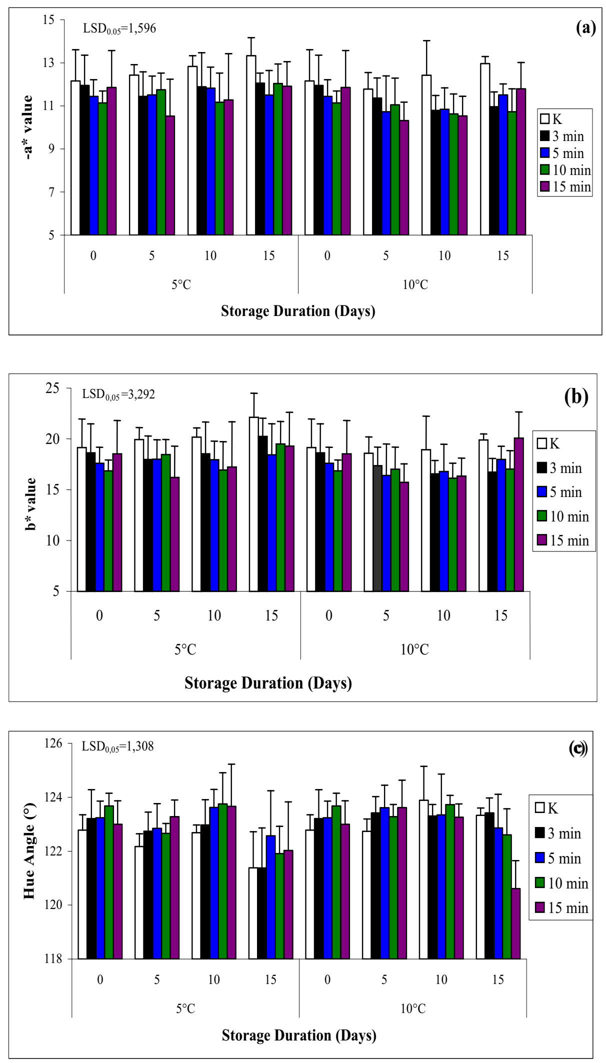

Figure 2. (a) -a* values, (b) b* values and (c) hue angles of cucumber treated with UV-C and control (K) samples during the storage. Each bar is the mean of four replications ± SE.

and b* values of samples. Hue angles of samples changed from 122.69 to 123.75° at 5°C and from 123.30 to 123.89° at 10°C at the 10th day of storage. However, differences among the treatments were not significant.

Total soluble solids content: Total soluble solids (TSS) content, although variable during storage period tended to remain between 4.20 and 4.43 in 5°C and between 3.57 and 4.18 in 10°C at the end of the storage (Fig. 3). In general TSS content of cucumbers stored at 5°C was higher than that of fruits stored at 10°C. UV-C treatments were effective on total soluble solids content of cucumber stored at 5°C, but TSS content of cucumber treated with UV-C was lower than that of control at 10°C after 15 days of the storage. Differences, however, among the treatments were significant neither at 5°C nor at 10°C.

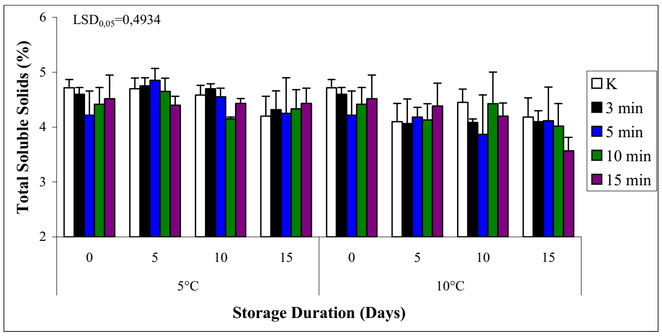

Figure 3. Total soluble solids of cucumber treated with UV-C and control (K) samples during the storage. Each bar is the mean of four replications ± SE.

Flesh firmness: Firmness loss would be more the result of the UV-C treatment. In general, UV-C treatments reduced softening of cucumbers during cold storage more at 10°C than at 5°C (Fig. 4). UV-C treatments for 10 min were most effective in maintaining the firmness of cucumbers after 10 days storage at 10°C. In 5°C, however, softening of cucumbers increased in all treatments, especially in samples treated with UV-C for 5 min during the storage, but no significant differences were obtained after 10 days of storage both at 5 and 10°C between control and those treated with UV-C for 3, 5, 10 or 15 min. At the end of the storage, the highest flesh firmness was observed in samples treated with UV-C for 3 min (3.76 lb) at 5°C whereas firmness was retained best in K treatment (4.54 lb) at 10°C.

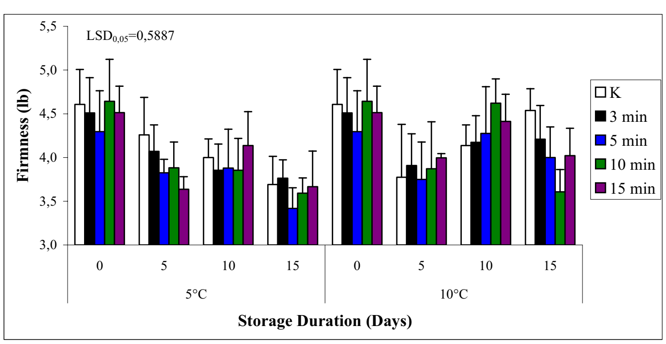

Figure 4. Flesh firmness of cucumber treated with UV-C and control (K) samples during the storage. Each bar is the mean of four replications ± SE.

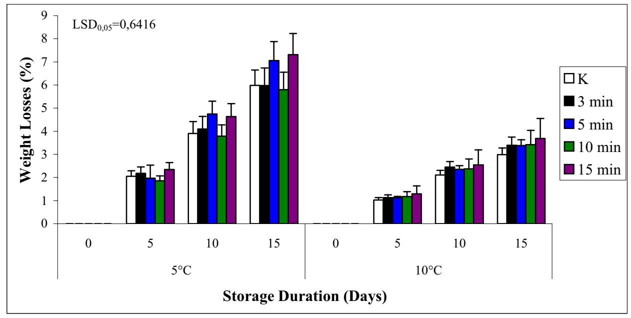

Figure 5. Weight losses of cucumber treated with UV-C and control (K) samples during the storage. Each bar is the mean of four replications ± SE.

Weight loss: Fig. 5 shows the weight loss of cucumbers after being stored for 15 days at 5 and 10°C. As expected, weight loss increased with a longer storage period and was more noticeable in all the treatments after 15 days at 5°C. The UV-C-treated cucumbers had higher weight losses than those in control both at 5 and 10°C during the storage. No significant differences in weight loss were observed among treated cucumbers with different treatment lengths.

Discussion

Electrolyte leakage can be used to determine changes in membrane permeability caused by environmental stress[17, 18]. In cucumbers, higher rates of ion leakage are associated with cell damage due to chilling injury [1, 19, 20] as well as other types of stresses. Although fruit exposed to chilling temperatures exhibit symptoms such as pitting, membrane alteration is the primary effect [5, 21]. Changes in membrane permeability, such as damage from the exposure to chilling temperatures, accumulate over time and do not occur immediately after exposure to chilling temperatures [20]. DeEll [5] reported that irreversible membrane injury due to chilling injury requires at least 7 d at 4.0°C (chilling temperature) in cucumber. The results presented here are in agreement with those of DeEll[5] since significant changes in membrane permeability were not evident until 10th day of the storage. At this time electrolyte leakage was increased particularly in K. So, chilling injury was began after the 10th day of storage. However, UV-C-treated cucumbers had lower electrolyte leakage than K at Day 10. Therefore, lower doses of UV-C treatments delayed chilling injury at the 10th day, but at the end of the storage, electrolyte leakage of cucumbers in K and in those treated with UV-C for 5 min was lower than in the other UV-C treatment. It was found by Gonzalez-Aguilar *et al.* [6] that the longer treatment, the greater the UV-C damage to the skin, observed as pink red strands throughout the fruit surface. Similarly, in cucumbers treated with higher doses of UV-C, we observed green-yellowish strands (data not shown). Consequently it was suggested that the higher electrolyte leakage of cucumbers treated with higher doses of UV-C correlated with this observation. Also it appears that the effectiveness of UV-C treatment is related to the dose applied and type of skin tissue of the fruit.

Changes in peel color are a natural development in horticultural commodities and part of the ripening and natural senescence process [22]. During this process carotenoids (and other pigments such as anthocyanins) replace chlorophylls [23] causing a degreening of the fruit. Changes in pigmentation can be accelerated by stress, such as chilling injury, but can also occur naturally during storage. In our study, green colour of cucumbers in K treatment naturally decreased by the length of the storage period. Varying the UV-C treatment had significant impact on the external peel color as measured by a*, b* and hue angle of stored Silor cucumbers. The color of cucumbers remained in UV-C-treated samples better than those of K treatment, but differences among the UV-C treatments were not significant. The b* values and hue angle of the samples were similar to a* values. So, UV-C treatments delayed yellowing of cucumbers both at 5 and 10°C.

Although some differences in soluble solids were observed at different intervals in the storage period, these differences were not systematic. Therefore, a clear effect of the UV-C treatments on soluble solids content of stored cucumbers could not be established. However, it was suggested that in UV-C-treated cucumbers total soluble solids (TSS) remained at 5°C higher than at 10°C. Sajnin *et al.* [24] reported total soluble solids content of 2.3°Brix on fresh cucumbers of unspecified cultivar, so TSS content of cucumbers both at 5 and 10°C was higher than this value. Therefore, it can be said that soluble solids content of cucumbers was affected by UV-C treatments. These values were also slightly higher than TSS values of 3.32-4.04 for greenhouse-grown cultivar Alara [25].

Stevens *et al.* [26] found that tomatoes with UV-C (1.3 kJm^{-2}) maintained firmness. However, Stevens *et al.*[10] observed that increasing doses of UV-C (254 nm) 10^4 erg mm^{-2} over the range of 0.8-40 times progressively reduced softening of peaches. We did not find any literature about cucumber treated with UV-C. So in this research, flesh firmness of cucumbers in 10°C firstly decreased in all treatments at 5th day and then increased until 10th day and again decreased. Fruit firmness was maintained high in K during the storage while UV-C treatments did not have noticeable effect on softening. The same trend was obtained on cucumbers in all treatments stored at 5°C.

In a previous study, it was observed that UV irradiation (248 nm) of 1 Jm^{-2} increased weight loss in peaches [27]. In our study, weight loss of cucumbers was higher at 5°C than at 10°C. So it was suggested that UV-C treatments caused damage of skin tissue in cucumbers (data not shown) and therefore weight losses increased at 5°C but remained low in cucumbers stored at 10°C. Weight loss of cucumbers stored at 10°C never exceeded 4% but reached 9% at 5°C.

Conclusions

UV-C treatments of cucumbers reduced electrolyte leakage and chilling injury until 10th day of storage, and also green color and firmness of cucumbers treated with UV-C was maintained high. Furthermore, there were no clear changes in total soluble solids content of samples, it was retained higher than in K treatment. So, UV-C treatments could be used to reduce chilling injury of cucumber.

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