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The Effect of UV-A / UV-B Radiation on Quality Changes of Harvested Curly Lettuce During the Storage

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ABSTRACT

This study investigated the effects of UV-A and UV-B radiation on curly lettuce quality. Results focused on colour, total phenolic content, antioxidant activity, and ascorbic acid. The findings revealed that the highest phenolic content (46.1 mg GAE/100 g FL) had been observed in lettuce samples treated with high dose UV-B on the 7th day. The lowest phenolic content (13.7 mg GAE/100 g FL) was recorded in those treated with low dose UV-B on the same day of storage. Data showed an increase of 29.7% in antioxidant activity and 53.7% in total phenolic content after 7 days of storage in samples treated with high dose UV-B. High dose UV-A radiation was found to be the most effective in maintaining and enhancing the ascorbic acid content of the lettuce. UV applications did not cause yellowing in the stored lettuce leaves. Further research on different doses and optimization is recommended.

Keywords: Ultraviolet A radiation, Ultraviolet B radiation, Lettuce, Quality characteristics

1. Introduction

The demand for freshly cut or minimally processed food products has increased recently. Processed products have become an essential part of the food market due to changing lifestyles and developing technology. Salads, widely consumed and generally defined as healthy, attract attention for this reason. Lettuce is one of the vegetables frequently used in ready-made salads, either alone or in combination. A leafy lettuce species known to originate from Turkey and the Middle East belongs to *Asteraceae* family (Das & Bhattacharjee 2020). Lettuce, which has health-promoting properties, contains certain bioactive components. These include ascorbic acid, carotenoids, phenolic compounds, and fibre. Lettuce also shows a significant oxygen radical scavenging capacity (Kim et al. 2016; Liu et al. 2007). Lettuce suffers a nutrient loss during harvest to the final consumer and deteriorates rapidly. Therefore, to protect human health, it is imperial to search for effective methods to enhance the biosynthesis of components with significant impact on health. Many researchers have investigated the phenolic structures and antioxidant properties of lettuce under environmental growing conditions (Llorach et al. 2004; Muscolo et al. 2022; Pérez-López et al. 2013) and storage conditions (Collado-González et al. 2022; Wang et al. 2022). Results for lettuce varied depending on the species and conditions. Significant product and nutrient losses occur in fruits and vegetables due to rapid aging and diseases in post-harvest storage. Post-harvest preservation has traditionally relied on refrigeration and chemical preservation technology (Usall et al. 2016). Food science and food industry developments led to new processing technologies enabling practical access to fresh and healthy foodstuffs in all seasons. Many new and developing technologies include aseptic packaging, controlled atmospheric packaging under vacuum, ozonation and recently UV radiation applications (Koutchma 2019). Since lettuce and other leafy greens continue to breathe after harvest, temperature, and humidity control are very important in storage. One of the most important functions of refrigeration is to control the respiration rate of vegetables and fruits. Uncontrolled respiration leads to the decomposition of sugar, fat, and proteins in the product cells and heat release. Loss of this type of stored food through respiration means reduced food nutritional value, loss of flavor, reduced salable weight, and faster spoilage. A food's respiration rate largely determines its transit and post-harvest life. The higher the storage temperature, the higher the respiration rate will be. For refrigeration to be effective in delaying spoilage, keeping the temperature in cold storage as constant as possible is important. Additionally, exposure to fluctuating temperatures can cause moisture accumulation (sweating) on the product surface, accelerating rotting. Storage rooms should be well insulated and adequately cooled, allowing air circulation to prevent temperature change. The best results can be achieved with vacuum or hydro-vac cooling for leafy products with a high surface/volume ratio, such as lettuce. The biggest disadvantage of these applications is the system cost. However, when choosing a current trend alternative, product qualities can be preserved in addition to the installation cost and practicality of UV-A and B

applications (Cefola & Pace 2023; Janghu et al. 2024). In UV applications, when factors such as radiation dosage, application surface and surface area, and application distance are selected per the food, it is possible to ensure the desired level of process efficiency. Otherwise, changes in genomics, lipid destruction, oxidative damage, changes in plant biochemistry and reduced growth, food toxicity and the risk of consumer illness due to the negative effects of radiation are inevitable (Guerrero-Beltr·n et al. 2004; Csapó et al.2019). In addition to numerous UV damage to plants, this radiation can sometimes induce the plants to synthesize useful compounds for humans (Jansen et al. 2008). UV radiation technology reveals two different beneficial effects on fruits and vegetables. The first effect is the inactivation of microorganisms in food products, which leads to elevated shelf life (Koutchma 2019). For this purpose, UV-C is frequently used to produce safe food. As a second beneficial effect, UV radiation technology produces some desirable results in improving the defenses of food products against microorganisms, increasing the content of ingredients with beneficial effects for health, extended shelf life, preservation, and improvement of sensory properties (Koutchma 2019). Azarafshan and colleagues' study (2020) showed that plants' secondary metabolites increased with increasing UV-B radiation. The research indicated that plants produce greater amounts of total phenols, flavonoids, and anthocyanin to counteract the effects of radiation, especially at high radiation intensities. Some pathways containing phenol, flavonoid, and anthocyanin increase activity in response to UV-B rays. For example, many of the enzymes in the phenylpropanoid pathway are activated by UV-B. The buildup of these compounds in the epidermal cell vacuoles blocks UV-B rays from penetrating into vulnerable leaf regions, particularly photosynthetic tissues. Additionally, due to their redox properties, these compounds could act as antioxidants, scavenging single oxygen and effectively inhibiting the oxidation of macromolecules like lipids, proteins, and nucleic acids to minimize plant damage (Azarafshan et al. 2020).

Therefore, UV radiation applications attract the attention of numerous researchers in terms of reducing product losses of fruits, vegetables, protecting, and improving bioactive plant components, nutritional values, and quality characteristics. Lettuce is among the examples, the nutritional and health properties of which could be increased based on the UV radiation source. UV technology application in lettuce mainly focused on post-harvest effects. To the best of our knowledge, there is only one study evaluating the possibility of applying UV-B radiation in packaging lines for fruit, vegetable, and root crops, including freshly cut "Iceberg" lettuce (Du et al. 2014). The aim of this study is to investigate the effects of varying doses of UV-A and UV-B radiation on colour change, total phenolic content, antioxidant activity, and ascorbic acid profile of curly lettuce, a lettuce species widely cultivated worldwide.

2. Methods and Material

2.1. Chemicals and reagents

L(+)-ascorbic acid, oxalic acid dihydrate, Folin–Ciocalteu reagent (FCR), 2,6-dichlorophenol-indophenol sodium salt hydrate, gallic acid, sodium carbonate (anhydrous Na_2CO_3), methanol were purchased from Merck (Darmstadt, Germany). Sodium bicarbonate puriss and 2,2-diphenyl-1-picrylhydrazil (DPPH) and methanol were obtained from Sigma-Aldrich (Darmstadt, Germany).

2.2. Selection of plant materials and UV treatment procedures

Curly lettuce (*Lactuca sativa* var. *crista*) was obtained from a lettuce grower in İnegöl/Bursa, Turkey in June 2021. Locarno / curly lettuce has green, curly leaves on the outside and a crisp white heart. The leaves have fairly mild flavors and a crispy texture. Curly lettuce was mature in full sun and partial shade and ready to harvest in 70 to 80 days. Lettuce harvested early in the morning was brought to the laboratory in a till basket within 2 hours immediately after harvest. The lettuce was stored at 10 ± 2 °C with air conditioning under laboratory conditions until UV treatment. The dented, rotten, and yellowed parts of the lettuce were removed before application. No pre-treatment was applied to the lettuce before UV employment. UV radiation was carried out on harvest day and under laboratory ambient conditions.

Curly lettuce was exposed to UV-A or UV-B radiation in an open front and back radiation chamber, coated with aluminium foil. The design of the chamber was modified based on recent publications (Allende et al. 2006; Salemi et al. 2021). Experiments were performed in a wooden UV radiation chamber (width: 70 mm, depth: 65 mm, height: 100 mm) equipped with two parallel UV-A (PL-L 36W/10/4P, Poland) or UV-B (PL-L 36W/01/4P, Poland) lamps. The distance of the lettuce from the lamps was 65 cm (Azarafshan et al. 2020). UV radiation intensity measurements were recorded via radiometer (Model PCEUV34, PCE Instruments UK Ltd., Deutschland) to determine the UV-A and UV-B intensities at 18 different locations in the application tray without blocking the light in the cabinet. The UV treatment conditions applied to the lettuce samples were varied by varying the exposure time. The UV lamps were turned on before use for 15 minutes to enable stabilization. The conditions applied during UV treatment and the experimental steps are illustrated in Table 1 and Figure 1.

Table 1- UV application procedure to lettuce leaves

UV Lamp	*Exposure Dose Stage*	*Exposure Dose (kJ m^{-2})*	*Exposure Time (min)*
UV-B	Low dose	1.52	4
UV-B	Medium dose	3.04	8
UV-B	High dose	4.56	12
UV-A	Low dose	1.52	4
UV-A	Medium dose	3.03	8
UV-A	High dose	4.55	12
Control	The samples were treated in the same manner without switching the UV lamps on.		

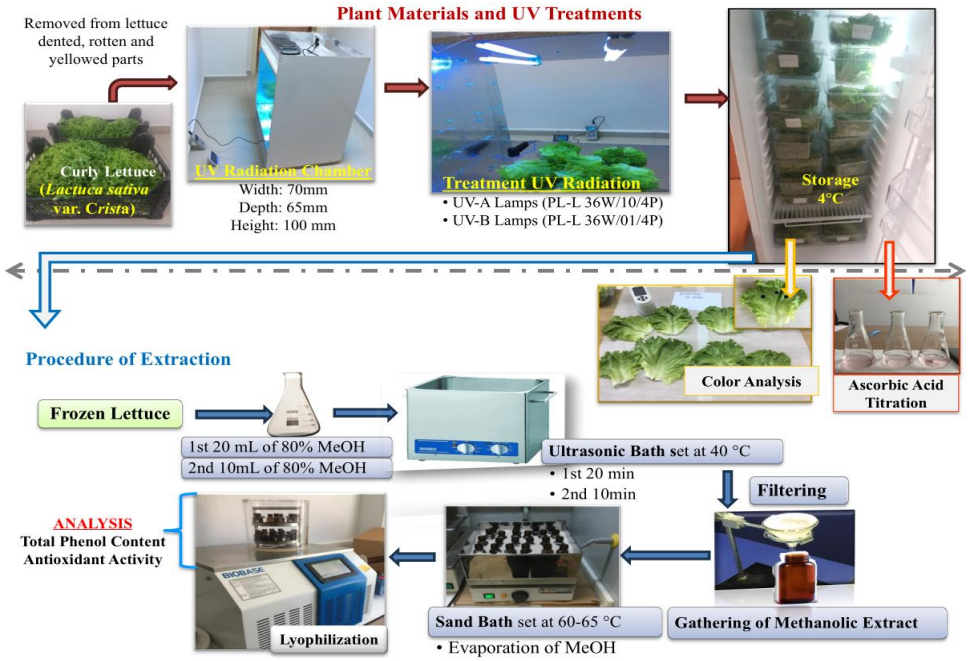

Figure 1- Experimental flow chart.

According to Du et al. (2014), lettuce samples deteriorated on the 10th day after UV application. In the literature survey and considering the fact that lettuce was a perishable product, samples were stored at 4 °C for a maximum of 7 days after UV application. After UV treatment, lettuce leaves (130-150 g) were placed in polyethylene terephthalate containers containing ventilation holes in the surface cover and stored in the refrigerator at 4±1 °C for 1, 3, or 7 days. Ascorbic acid determination and colour analysis were performed on the 1st, 3rd, and 7th days. The remaining lettuce leaf samples were frozen and stored at −82 °C until further analysis.

2.3. Colour analyses

The colour of treated and stored lettuces was measured with the Chroma Meter NR-200 (Shenzhen 3NH Technology Co., Ltd., China). Readings were conducted from three different points of lettuce leaves. This procedure was repeated at least three times. The differences with untreated control samples were calculated in terms of ΔL^*, Δa^*, and Δb^* in the lettuce samples exposed to different doses of UV radiation and the storage period. The total colour difference (AE) for each sample was calculated using the following equation (Pathare et al. 2013):

$$\Delta E = \sqrt{[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]}$$

The L^* coordinates represent the lightness-to-darkness scale, ranging from white to black. The a^* and b^* coordinates represent the colour's chromaticity, with the a^* axis varying from green to red and the b^* axis varying from blue to yellow. $\Delta E_{process}$ and $\Delta E_{storage}$ were the two types of colour differences calculated in analyses. In $\Delta E_{process}$, the colour difference values were calculated by comparing the control samples among themselves on the same storage day. On the other hand, $\Delta E_{storage}$ was determined by measuring the colour difference values compared to 0th-day samples within the same UV treatment groups.

2.4. Ascorbic acid determination

The amount of ascorbic acid in curly lettuce was determined via the titrimetric method utilizing 2,6-dichlorophenolindophenol solution (Nadkarni 1965).

2.5. Extraction method

For the determination of antioxidant activity and total phenolic content, 5-6 g of each frozen lettuce sample were extracted with 20 mL 80% aqueous methanol for 20 minutes at 40 °C in an ultrasonic bath and filtered using Whatman No. 1 filter paper. This process was carried out in two stages, and the filtrates were combined in an amber tube. The methanol fraction of the mixture was evaporated in a sand bath (60-65 °C) and then the remaining aqueous extracts in amber bottles were dried via Lyophilization (Biobase, China) at -56 °C under mbar vacuum pressure for 24 h (Llorach et al. 2004). Lyophilized extracts of the lettuce samples in amber bottles were kept in the refrigerator until analysis.

2.6. Total phenolic content

The total phenolic content was determined by the Folin-Ciocalteu method (Tomás-Callejas et al. 2012). 30-35 mg samples were freeze-dried and then homogenized in 5 mL of 80% methanol solution via ultrasonic bath. The lettuce extracts (200 µl) were mixed with 1.5 mL of Folin-Ciocalteu reagent (previously diluted 10-fold with distilled water) and vortexed. 1.2 mL of 7.5% (w/v) Na_2CO_3 solution was added to this solution. The resulting mixture was kept in the dark for 90 min at room temperature. The absorbance was measured at 765 nm with a UV/VIS spectrophotometer (AgileSpec). A standard curve of gallic acid solution (0.005-0.15 mg mL^{-1}) was prepared using a similar procedure and quantification was done concerning this standard curve (R^2= 0.9986). The final quantitative results were expressed as mg gallic acid equivalent (GAE)/g of fresh lettuce (FL).

2.7. Total *antioxidant activity*

The DPPH radical scavenging assay was conducted following the method of Kang & Saltveit (2002) with some modifications. The ability to scavenge the DPPH radical was the main factor in measuring the antioxidant activity of the extract. 1 mL sample from 0.07 mg lettuce mL^{-1} solution containing 80% aqueous MeOH and 2 mL of DPPH solution was added and vortexed. The absorbances of the colours formed as a result of the reaction in the solutions. The aliquots were kept in the dark for 30 minutes at room temperature, absorbances were recorded at 517 nm in a UV/VIS spectrophotometer (AgileSpec) with MeOH used as the blank. The DPPH concentration in the lettuce sample medium was calculated using the calibration curve (R^2= 0.9972) prepared using the DPPH standard (0.008 and 0.04 mg mL^{-1}). The free radical scavenging effects of the lettuce extracts were given as the concentration (EC_{50} µg mL^{-1}) at which 50% of the DPPH was scavenged.

2.8. Statistical analysis

The data were expressed as means ± SD and the statistical evaluation was performed using SPSS 22.0 (SPSS Inc., USA). A comparison was made between UV treatment groups or storage using the one-way analysis of variance (ANOVA). The significance of differences was conducted with the Tukey Honestly Significance Difference test ($P<0.05$).

3. Results and Discussion

3.1. Effects of UV radiation on colour change of curly lettuce

The colour of fruits and vegetables is one of the crucial factors used in evaluating the quality of products. Colour is also the main factor affecting the preferences of consumers. Technically, instrumental colour analysis is determined by spectrophotometric approaches, in which the observed colour can be expressed numerically. The effect of UV treatments and storage on L*, a* and b* values in lettuce leaves were illustrated in Figure 2. The changes of L* and a* values in lettuce leaves treated with UV were statistically not significant ($P>0.05$). However, storage was found to have an altering effect on the total colour change of treated samples. The initial L* value of control samples was 52.1. It was determined that the brightness (L* value) of lettuce samples treated with high dose UV-A and medium dose UV-B had increased on the 3rd and 7th days of storage (Figure 2c).

The a* value of control samples was -9.1 at the beginning of storage. The only statistically significant increase (3rd day: -9.4; 7th day: -10.1) in the green colour of lettuce (a* value) leaves was in the case of high dose UV-A application during storage (Figure 2a). UV radiation and storage did not cause any yellowing change (b value) in the lettuce samples (Figure 2b). Literature survey revealed various result regarding the colour change upon UV- treatment. Kasim & Kasim (2017b) reported the yellowing of spinach. Similar yellowing results were obtained in the work of Aiamla-or et al. (2010) with broccoli. On the other hand, the effect of UV-B application seemed to be variant. Kasim & Kasim (2017a) reported an increase of the red colour of capia peppers. Consequently, the results obtained for UV-B radiation seemed to be independent of the type of vegetable investigated in the studies.

On the other hand, further literature investigation revealed results like those obtained in the present study. UV employment preserves the colour of green-coloured (such as lettuce) fruits and vegetables due to the suppression of chlorophyll degradation, the most common abiotic stress observed by UV treatment (Aiamla-or et al. 2010). This was the case in the present study and similar results were obtained in the work of Aiamla-or et al. (2009). They reported that UV-B application had delayed the yellowing of broccoli flowers, while yellowing had been inevitable in the presence of UV-A application.

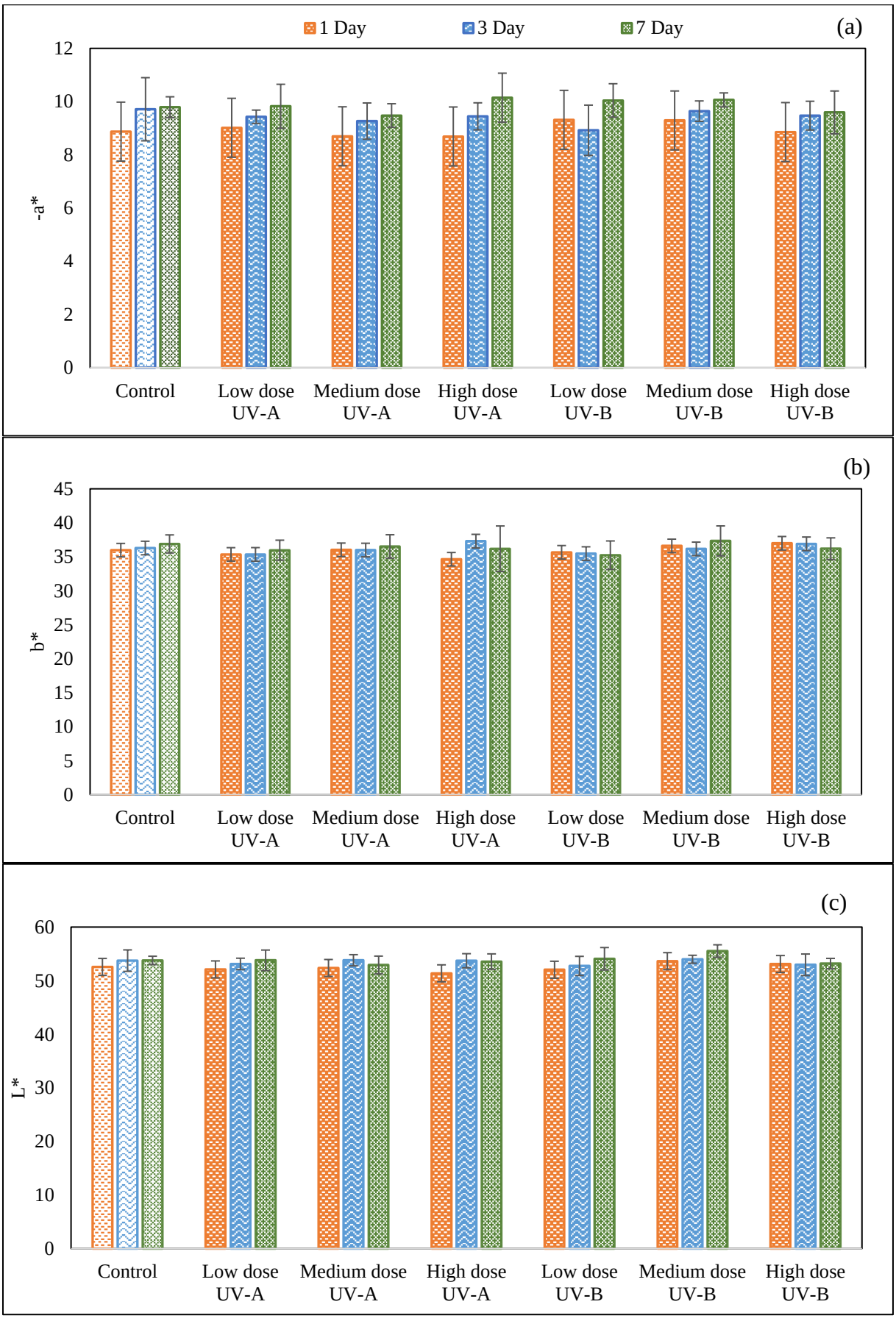

Figure 2- Effect of UV-A or UV-B treatment on lettuce during storage: Changes in (a) red to green colour, a*; (b) yellow to blue colour, b* and (c) lightness to darkness, L* values.

The ΔE values given in Tables 2 and 3 represented the colour changes relative to the initial values. Following UV radiation exposure, the ΔE values in lettuce leaves ranged from 1.17 to 3.00 (Table 2). Throughout the storage period, colour changes were determined within the range of 1.33 to 4.11 (Table 3). However, these colour changes were not statistically significant (P>0.05), indicating that the UV treatments had not been effective in inducing noticeable alterations in colour. Figure 3 illustrates the lettuce samples after 7 days of UV-A and UV-B rays exposure.

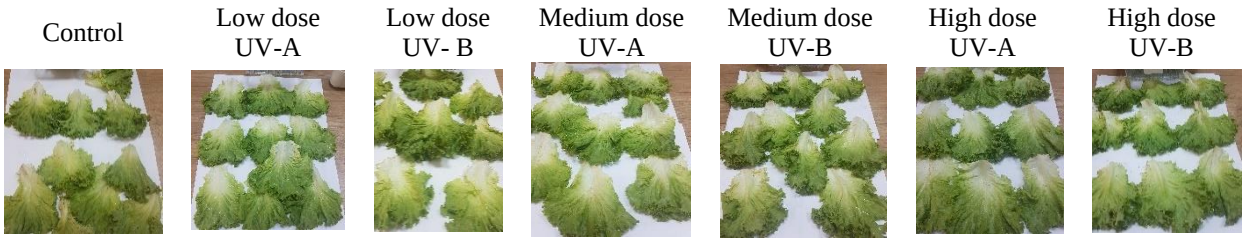

Figure 3- Effects of different doses UV-A and UV-B on the colour of lettuce at the end of the 7th.

Table 2- Effect of UV treatments on the total colour difference of lettuce, ($\Delta E_{process}$).

$\Delta E_{process}$	*Low dose*		*Medium dose*		*High dose*	
	UV-A	*UV-B*	*UV-A*	*UV-B*	*UV-A*	*UV-B*
1st Day	2.14 ± 0.46	2.53 ± 1.46	1.17 ± 0.63	2.16 ± 0.96	3.00 ± 1.32	2.37 ± 1.54
3rd Day	2.54 ± 0.62	2.93 ± 1.27	1.80 ± 1.54	2.16 ± 0.91	2.61 ± 2.7	1.82 ± 1.19
7th Day	2.03 ± 0.98	2.72 ± 1.07	2.22 ± 1.13	2.55 ± 1.65	1.75 ± 0.62	2.36 ± 1.16

Table 3- Effect of storage on total colour difference of applied lettuce, ($\Delta E_{storage}$).

Applied dose	*UV lamp*	$\Delta E_{storage}$		
		1st Day	*3rd Day*	*7th Day*
Low	UV-A	2.00 ± 0.51	2.14 ± 1.54	2.60 ± 0.92
	UV-B	2.30 ± 1.69	2.61 ± 1.25	2.88 ± 1.53
Medium	UV-A	1.33 ± 0.57	2.29 ± 1.79	2.13 ± 1.56
	UV-B	2.43 ± 1.12	2.73 ± 1.48	4.11 ± 2.15
High	UV-A	2.84 ± 1.05	3.30 ± 2.75	2.28 ± 1.06
	UV-B	2.66 ± 1.59	2.19 ± 1.15	2.47 ± 1.29
Control		2.65 ± 0.86	2.14 ± 1.05	2.26 ± 1.25

3.2. Effects UV radiation on ascorbic acid in curly lettuce

Lettuce is an important source of ascorbic acid, and the increased radiation intensity during lettuce production accelerates the synthesis of vitamin C by promoting the activity of enzymes involved in vitamin C metabolism in plant leaves (Martínez-ispizua et al. 2022). Ascorbic acid amounts of lettuce samples are given in Figure 4. Results indicated that UV-A and UV-B application doses and storage had affected the amount of ascorbic acid (P<0.05). The average initial amount of ascorbic acid in the control samples was 32.5 mg/100 g FL. The amount of ascorbic acid in untreated lettuce leaves decreased to 31.2 mg/100 g FL after 7 days of storage at 4 °C. Post-harvest storage causes deterioration of ascorbic acid in lettuce samples over time. However, the vitamin C content increased on the 7th day of storage in all lettuce samples with UV treatment, except for the moderate UV-B application.

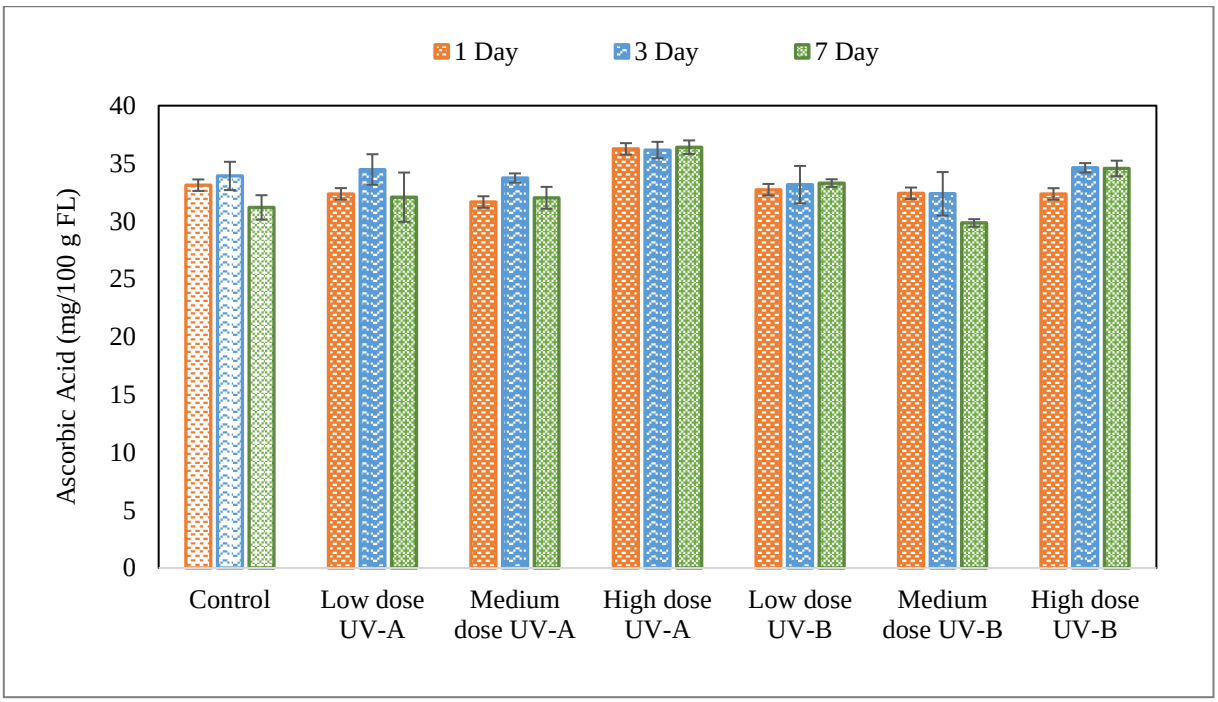

Figure 4- Effect of UV-A or UV-B treatment on total ascorbic acid content of lettuce during storage at 4 °C. Ascorbic acid content of control samples on day 0: 32.5 ±0.5 mg/100 g FL.

The amount of ascorbic acid in lettuce varies according to species, pre-harvest and post-harvest factors (Nicolle et al. 2004). Mampholo et al. (2016) reported that the ascorbic acid content in curly lettuce species had varied between 13.39 and 26.5 mg/100 g FL. The amount of ascorbic acid was higher than the control samples of the present study. Ascorbic acid has high UV absorption in the 200-280 nm germicide wavelength range. Photochemical reactions at these wavelengths may lead to photodegradation (Koutchma 2009; Tikekar et al. 2011). In this study, when the effects of UV-A and UV-B applications were evaluated, high rates of losses in ascorbic acid amounts should not be expected since ascorbic acid does not absorb light significantly at wavelengths above 300 nm (Koutchma 2009).

The amount of ascorbic acid in the UV-A treated lettuces was significantly higher than the control samples at the end of 7 storage days. The amount of ascorbic acid in lettuce leaves exposed to high dose UV-A was the highest at 36.4 mg/100 g FL, indicating a 12% increase. The amount of ascorbic acid was higher in the lettuce samples treated with low and high UV-B levels than the control samples on the 7th day of storage. Similarly, it was determined that the ascorbic acid content increased in products such as apples (Hagen et al. 2007) and tomatoes (Castagna et al. 2013) after UV-B applications. In contrast, Liu et al. (2011) reported that UV-B radiation negatively affected the ascorbic acid content in green ripe tomatoes after harvest. Literature results reveal that each study should be evaluated on a product basis.

3.3. Effects of UV radiation on total phenolic content and antioxidant activity in curly lettuce

Lettuce is a vegetable that contains significant antioxidant activity and phenolic content. The main compounds are phenolic acids found especially in green leafy lettuce (Das & Bhattacharjee 2020). Short-term exposure to environmental factors, agricultural practices, and stress factors could also be employed to improve important nutritional values and antioxidant capacity. On the other hand, the total phenolic content and antioxidant activities vary depending on the species and colour of lettuce (Martínez-Ispizua et al. 2022; Nicolle et al. 2004). The change of total phenolic content of the lettuce expressed as mg GAE with UV-A and UV-B dose and storage was illustrated in Figure 5a. Control lettuce samples had a mean total phenolic content of 14.2 ± 0.7 mg GAE/100 g FL. The total amount of phenolic content in control samples reached the highest level (41.8 ± 1.4 mg GAE/100 g FL) on the 1st day of storage. At the end of the storage, the total phenolic content ranged between 27.0 and 33.0 mg GAE/ 100 g FL.

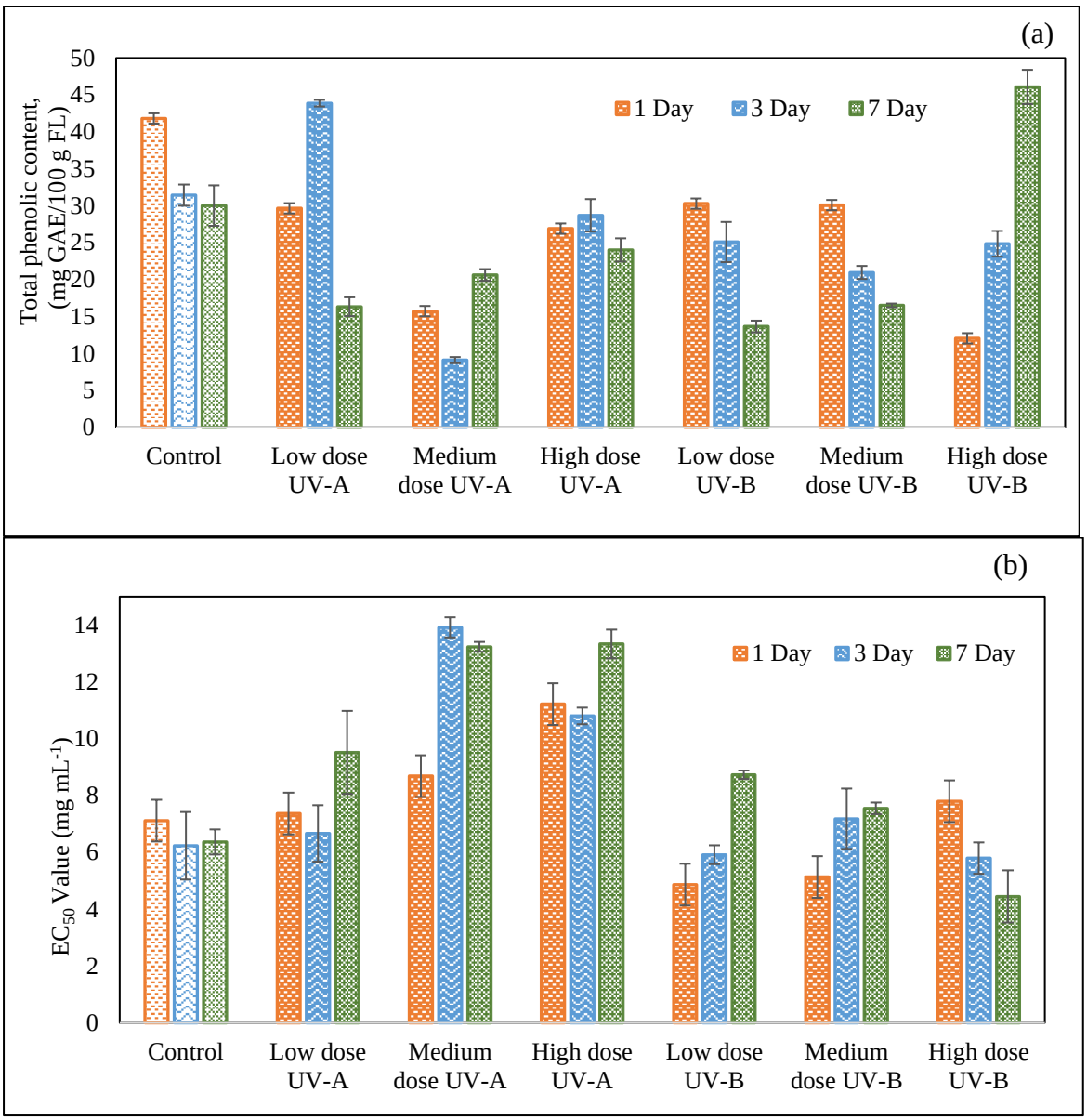

Figure 5- Effect of UV-A or UV-B treatment on lettuce during storage at 4 °C. Changes in (a) total phenolic content of lettuce, (b) EC_{50} value of lettuce. Phenolic content of the control samples on day 0: 14.2 ±0.7 mg GAE/100 g FL. EC_{50} value of the control samples on day 0: 12.2 ±0.7 mg mL^{-1}.

The total phenolic amount was statistically affected by post-harvest UV-A and UV-B applications. The total phenolic content in fruits and vegetables should increase depending on the light-induced stress conditions. The effect of UV radiation on phenolic content in fruits and vegetables depends on the product type, UV type, radiation dose, incubation time, and environmental factors (Du et al. 2014; Nguyen et al. 2014; Scattino et al. 2016). The responses obtained in the biochemical properties of the products might have varied positively or negatively depending on UV radiation, which was an abiotic stress factor (Jansen et al. 2008). Therefore, it was important to evaluate the persistence of the response effects and the parameters of the product depending on various factors.

The phenolic content in lettuce samples treated with all doses of UV-A and low-moderate doses of UV-B decreased during storage. On the other hand, the total phenolic content in the lettuce leaves treated with high dose UV-B increased by 53.7% after 7 storage days. The results obtained in the present study were similar to the literature. In the study conducted by Du et al. (2014), an increase of approximately 66% in total phenolic content was found on the 6th day in the lettuce samples related with low dose UV-B. Results also indicated an approximately 150% increase in lettuce's total phenol amount in the case of medium-high dose UV-B on the 6th day (Du et al. 2014). Hence it was implied that high total phenolic content requires further storage periods.

In this study, the total phenolic content of lettuce leaves treated with high dose UV-B was better compared to control samples. In addition, a decrease in the total amount of phenol was detected in low and moderate UV-B and UV-A treatments on the 7th day of storage compared to the control samples in this study. Although the total phenolic content of lettuce varied quantitatively and qualitatively according to the lettuce species, it was thought that such different effects might have occurred as the effects in

UV applications had been related to the absorbed doses. Interdonato et al. (2011) stated in their study that different types of plants had exhibited irregular behavior and therefore had reacted differently to increased UV radiation due to variant UV absorbers in plant structure. Similarly, Scattino et al. (2016) obtained variant results with UV-B treatment. The total phenol amounts of peaches both increased and decreased which was related to varying genotypes.

Antioxidant activities in lettuce samples were calculated using the EC_{50} value, an indicator of the amount of antioxidants required to scavenge 50% of DPPH concentration. Results indicated higher antioxidant activity of the sample in the case of a lower calculated EC_{50} value. UV treatments and storage time caused a statistically significant difference (0.05) in antioxidant activities in lettuce samples. The EC_{50} value of the control lettuce samples was 12.2 mg mL^{-1}. EC_{50} values decreased in the control samples on the 1st day of storage. Since the low EC_{50} value was an indicator of high antioxidant activity, it was determined that the antioxidant compound accumulation had increased on the 1st day of storage and had been preserved afterwards (Figure 5b).

High dose UV-B application increased antioxidant activity, and the EC_{50} value was the lowest (4.5 mg mL^{-1}) on the 7th storage day. High dose UV-B application increased the antioxidant activity by 29.7% compared to the control samples on the 7th storage day. Low and medium doses of UV-B applications increased the antioxidant capacity temporarily on the 1st day, however the values decreased on the 3rd and 7th storage days. Similar to our results, Formica-Oliveira et al. (2017) detected increases in antioxidant capacities at different levels of UV-B exposure applied to broccoli leaves, stems, and crown parts. It was determined that the lettuce samples, treated with medium and high doses of UV-A, had the lowest DPPH radical scavenging effects on the 7th day with the highest EC_{50} values of 13.2 mg mL^{-1} and 13.3 mg mL^{-1}, respectively.

Increases and decreases in the amount of total antioxidant substance during storage were similar to the changes in total phenolic content. However, a linear correlation was not detected between the results. The differences were related to the changing characteristics of the plant. The total amount of phenol in green lettuce constitutes more than 60% of the total antioxidant capacity, while the amount of ascorbic acid was responsible for 3.2%-24.5% of the antioxidant capacity (Nicolle et al. 2004).

As scientists have declared, exposing plants to UV may cause abiotic stress. Plants respond to stress by revving up their production of their own natural enzymes. As the production of enzymes increases, levels of phenolic compounds and antioxidants synthesized by the enzymes also increase. Despite this and other knowledge about plants' responses to stress and UV-B, the idea of using UV-B to quickly, safely, and conveniently enrich the antioxidant heft of fresh produce has not been extensively studied (Paul et al. 2012; Espinosa-Leal et al. 2022).

4. Conclusions

The demand for freshly cut or minimally processed products has increased in the world food markets. This demand leads to an increase in fruit and vegetable production. However, the increase in production has brought many problems regarding the maintenance of product quality throughout the processes reaching the consumer, and the problems have necessitated a new approach to the subject. In today's world, where modern technologies are applied, there is a struggle to minimize the loss of nutrients and food properties with the use of ultraviolet light applications; one of the most recent technologies in post-harvest storage of fruits and vegetables.

Accordingly, lettuce, one of the most commonly used vegetables in ready-to-eat salads, was treated with UV-A and UV-B at determined intensities and doses to clarify their effects on quality characteristics during storage. It was statistically shown that UV-A and UV-B application doses and storage periods had been effective on quality characteristics such as colour, ascorbic acid, antioxidant activity, and total phenolic matter. However, UV dose applications showed variant trends in each quality value. The ascorbic acid loss of UV-treated lettuce was negligible. The high-dose UV-A application was the most effective application in terms of protection and improvement of the ascorbic acid amount. As a result of high-dose UV-A, the amount of ascorbic acid increased by 16.7% compared to the control sample. On the other hand, high dose UV-B enabled ascorbic acid to increase by 10.9% compared to the control sample. In terms of total phenolic content, the highest values were obtained in lettuce treated with high dose UV-B after 7 storage days. There was a 53.7% increase in the total phenolic content in high-dose UV-B treated lettuce samples compared to control. Similarly, it was determined that a high dose of UV-B was effective in increasing the antioxidant activity of lettuce, and antioxidant activity increased by 29.7% on the 7th storage day compared to control.

As a result, it was shown in this study that lettuce samples exposed to UV-A and UV-B light might have the potential to be used to maintain or improve some quality features. Among the three doses of UV-A and UV-B treatments, high-dose treatments had been more effective. However, more studies are needed to illuminate the effects of UV-A or UV-B on food product contents in general. In future studies, it is thought that optimization of different doses of UV-A and UV-B would have been beneficial in the context of process conditions and UV-treated food products. Innovative application solutions create value in lettuce within a storage period that otherwise might be lost or wasted. Good UV-A and B applications are key to maintaining quality, preserving nutrient content, gaining higher market prices, and reducing losses of fresh produce. Considering that almost half of the vegetables are wasted before they can be sold, interventions related to post-harvest handling are also economically important.

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