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Research Article

# UV-C effect on postharvest quality of citrus fruits from the northeastern region of Valle del Cauca, Colombia

Efecto de la UV-C en la calidad postcosecha de cítricos de la región nororiente del Valle del Cauca, Colombia

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## ABSTRACT

Ultraviolet short wave (UV-C) irradiation is an emerging technology employed in postharvest fruits treatment. This method facilitates a reduction in microbial load, triggers an elicitor effect, and prolongs the shelf life of fruits. The aim of this research was to assess the impact of UV-C treatment on the physicochemical parameters, morphology, and surface color of the primary citrus fruits cultivated in the northeastern region of Valle del Cauca, Colombia. Fruits of rangpur red lime, Tahitian lime, and sweet orange cv. 'Sweety' were irradiated with UV-C for 5 min. A positive control involved samples treated with a 150 mg/L sodium hypochlorite solution for 5 min, while the negative control comprised samples without any postharvest treatment. Subsequently, the fruits were stored in plastic baskets for 21 d at 26 °C with a relative humidity of 70 %. The results revealed that UV-C application effectively delayed maturation, prevented granulation, and maintained the physicochemical parameters, morphology, and surface color of citrus fruits during storage. In conclusion, UV-C shows promise as a technology for treating citrus fruits during the postharvest stage, offering a means to mitigate losses, and assuring food availability.

**Keywords:** Fruit irradiation; ultraviolet short wave; storage at room temperature; physicochemical analyses; color measurement.

## RESUMEN

La irradiación con ultravioleta de onda corta (UV-C) es una tecnología emergente empleada en la postcosecha de frutas. Este método facilita la reducción de la carga microbiana, genera un efecto elicitor, y prolonga la vida útil de frutas. El objetivo de esta investigación fue evaluar el impacto del tratamiento UV-C sobre los parámetros fisicoquímicos, morfología y color de la superficie de los principales cítricos cultivados en la región nororiental del Valle del Cauca, Colombia. Los frutos de limón mandarino, limón Tahití y naranja dulce 'Sweety' fueron irradiados con UV-C por 5 min. Un control positivo incluyó muestras tratadas con una solución de hipoclorito de sodio de 150 mg/L durante 5 minutos, mientras que el control negativo incluyó muestras sin ningún tratamiento postcosecha. Posteriormente, los frutos se almacenaron en cestas plásticas durante 21 d a 26 °C con una humedad relativa del 70 %. Los resultados revelaron que la UV-C retrasó la maduración, previno la granulación, y mantuvo parámetros fisicoquímicos, morfológicos, y el color superficial de los cítricos durante su almacenamiento. En conclusión, la UV-C se mostró como una tecnología prometedora para el tratamiento de cítricos durante la postcosecha, disminuyendo pérdidas y asegurando la disponibilidad de alimentos.

**Palabras clave:** Irradiación de frutas; ultravioleta de onda corta; almacenamiento a temperatura ambiente; análisis fisicoquímicos; medición de color.

## INTRODUCTION

Citrus fruits, members of the *Rutaceae* family, are primarily consumed fresh or used as raw materials for juices, due to their sensory qualities such as color, bitterness, and astringency. They are also rich in vitamin C and various secondary metabolites, including flavonoids, limonoids, carotenoids, phenolic acids, and essential oils. Additionally, they provide essential micronutrients like sugars, dietary fiber, and minerals (Lv et *al.*, 2015). Globally, citrus fruits are the second most produced fruit, among them, oranges are the most significant, followed by tangerines, limes, and lemons. China, Brazil, and India are the leading producers of citrus fruits (Pereira Gonzatto and Scherer Santos, 2023). In Colombia, citrus production reaches up to 600,000 tons annually, with the northeastern region of Valle del Cauca, particularly Caicedonia and Sevilla, contributing about 7,000 tons per year (Agronet, 2024). The main citrus varieties harvested in this area include Tahitian lime, orange cv. 'Swetty,' and rangpur red lime for domestic consumption (ICA, 2019).

In the northeastern region of Valle del Cauca, one of the challenges facing local citrus marketing is that fruits are stored, transported, and distributed at ambient temperature in plastic baskets without protection measures. Some producers opt to wash the fruits using water or sodium hypochlorite solutions as conventional post-harvest treatments. According to Sun *et al.* (2012), chlorine (sodium hypochlorite), is among the most used sanitizers for fruits, typically in solutions with concentrations ranging from 50 to 200 mg/L, to help maintain the quality of fruits by reducing microbial

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populations. However, chlorine has the potential to react with organic matter, forming carcinogenic by-products, and to contaminate affluents (Mishra *et al.*, 2018).

Emerging technologies such as edible coating and films, modified atmosphere packaging, application of natural preservatives and antimicrobials, high hydrostatic pressure, ozone, and ultraviolet short wave (UV-C) have been proposed for prolonging fruits quality and safety during storage, owing to their human and environmental benefits (Iturralde-García *et al.*, 2022). In the case of UV-C, its application through irradiation helps reduce microbial load and generates an elicitor effect on fruits. The effectiveness of UV-C application depends on factors such as the distance between the fruit and the lamp source (100-280 nm), fruit shape and surface characteristics, and the duration of treatment (Garzón-García *et al.*, 2020).

Pristijono *et al.* (2019) exposed Tahitian limes to UV-C irradiation and observed that this pre-storage treatment preserved the quality during storage at 10 °C for about 28 d. This preservation was achieved through a reduction in ethylene production, a decrease in the respiration rate, a delay in maturation, and an increase in overall acceptability. UV-C irradiation of minimally processed 'Satsuma' mandarins resulted in an increase in antioxidants and bioactive compound content while preserving quality attributes such as total soluble solid content, pH, titratable acidity, and ascorbic acid content (Shen *et al.*, 2013).

Based on the aforementioned information, the aim of this research was to assess the impact of UV-C treatment on the physicochemical parameters, morphology, and surface color of the primary citrus fruits cultivated in the northeastern region of Valle del Cauca, Colombia.

## MATERIAL AND METHODS

### Plant material

The fruits of rangpur red lime (*Citrus* × *limonia*), Tahitian lime (*Citrus* × *latifolia*) and sweet orange (*Citrus sinensis*) cv. 'Sweety' were obtained from local farms in the municipality of Caicedonia, Valle del Cauca, Colombia. Approximately 4, 3.8, and 10 kg of rangpur red lime, Tahitian lime, and sweet orange, respectively, were taken for analysis after being collected in initial stages of maturation.

### Postharvest treatments and storage conditions

The fruits of each species were divided into three lots. The first lot (control) consisted of fruits without treatment. The second lot was immersed for 5 min in a 150 mg/L sodium hypochlorite solution, drained and left to dry for 10 min (Sapers, 2014). UV-C radiation was applied to the third lot (Garzón-García *et al.*, 2023). Groups of six fruit were kept for 5 min under a 20 W UV lamp (UVC20W, ANTIVID19, Ecolite S.A.S, Cali, VAC, CO). The radiation source was located 11 cm above the work area (Figure 1). After treatments, the fruits were distributed in nine containers divided into species and treatments. These were stored under ambient conditions (26 °C with a relative humidity of 70 %) for 21 d, simulating storage at local shops.

**Figure 1.** Arrangement of a rangpur red lime lot for UV-C treatment.
**Figura 1.** Disposición de un lote de limón mandarino para el tratamiento con UV-C.

### Analyses of pH, titratable acidity, and total soluble solid content

pH of samples was measured with a pH meter (HI 991001, HANNA Instruments, Woonsocket, RI, US). Titratable acidity (TA) was measured according to the AOAC 942.15 method, utilizing phenolphthalein as an indicator, and titrating with 0.1 N NaOH until a pH of 8.1 was achieved. Citric acid was considered as the primary organic acid (AOAC, 2012). Total soluble solid content (TSS) was assessed by using a digital refractometer (PAL-1, ATAGO CO., TYO, JP).

### Fruit length, width, and weight

Equatorial diameter (ED or width) and polar diameter (PD or length) were determined using a caliper, following the methodology of Kadluczka and Grzebelus (2022). Fresh weight of samples was measured with a precision balance (Xtar, Lexus, UP, IN). Fruits were weighed at day 0, 7, 14, and 21 of storage. The difference between the initial and final weight was expressed as weight loss percentage (WL %) during a storage interval (Peralta-Ruiz *et al.*, 2020).

$$WL\ \% = \frac{\text{Initial weight} - \text{Weight during sampling}}{\text{Initial weight}} \quad (1)$$

**Measurements of color parameters**

The peel color of fruits was assessed using a 3NS800 spectrophotometer (3NH, Zengcheng District, GZ, CN), calibrated with a D65 illuminant and a 10° observer angle. Measurements were presented in CIELab coordinates (L* or lightness: white(+)/black(–), a*: red(+)/green(–), b*: yellow(+)/blue(–)) and hue (h*; 0° or 360°: red, 90°: yellow, 180°: green, and 270°: blue). Hue and yellow index (YI) were calculated according to Pathare *et al.* (2013).

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

$$YI = \frac{142.86b^*}{L^*}, \quad (3)$$

**Experimental design and statistical analysis**

A completely randomized design with two factors and a 3×4 factorial arrangement was used for each species. The first factor was the postharvest treatment: Control (C), immersion in a sodium hypochlorite solution (SH), and UV-C exposition (UV). The second factor corresponded to the sampling time during storage (0, 7, 14, and 21 d). A two-way ANOVA and a Tukey's test were performed to assess differences in mean values between treatments and the effect of factors on pH, TA, TSS, width, length, percentage of weight loss and color parameters of rangpur red lime, Tahitian lime, and sweet orange ($p < 0.05$). The results of these tests were presented as the mean of triplicate measurements ± standard deviation in the tables, and as the mean ± standard error in the figures. The relationship between TA, TSS, width, length, and percentage of weight loss was established by means of a correlation matrix and the calculation of the Pearson correlation coefficient (ρ). All analyses were performed in Minitab 17 (Minitab Inc, State College, PA, US).

## RESULTS AND DISCUSSION

**pH, titratable acidity, and total soluble solid content**

Figure 2 illustrates the results of the determination of pH, titratable acidity, and total soluble solid content of rangpur red lime, Tahitian lime, and sweet orange subjected to different postharvest treatments. According to the two-way ANOVA, the postharvest treatment, the storage time, and the interaction of these factors had a significant effect on physicochemical properties of rangpur red lime and Tahitian lime ($p < 0.05$). Values of pH corresponding to rangpur red lime (C: 2.45 - 2.33, SH: 2.45 - 2.25, UV: 2.45 - 2.32) and Tahitian lime (C: 2.67 - 2.42, SH: 2.67 - 2.28, UV: 2.67 - 2.41) decreased slightly during storage. However, these values were within the ranges reported for citrus fruits. Mohd-Hanif *et al.* (2016) noticed no significant changes in pH of lime (*Citrus aurantifolia*) juice irradiated with different UV dosage (from 22.76-44.24 mJ/cm$^2$). This last finding might be attributed to the fact that lime juice was not stored for an extended period, as opposed to the whole fruit storage duration in the current study.

TA tended to decrease until day 14 of storage, while TSS content increased throughout the storage period. Concentration of organic acids and sugars in citrus fruits depend on ripening stage, environmental conditions, and agronomical practices (Asencio *et al.*, 2018). Generally, organic acids accumulate during early stages of fruit ripening and storage, while sucrose levels are increasing (Liao *et al.*, 2019). In a separate study, sweet oranges (*Citrus sinensis* (L.) Osbeck) were irradiated using ultraviolet light for six d after harvest, causing a remarkable increase in sucrose, fructose, and glucose content (Hu et *al.*, 2019). On the other hand, any factor had effect on physicochemical properties of sweet orange ($p>0.05$). Considering that pH (C: 3.47 – 3.48, SH: 3.47 – 3.59, UV: 3.47 – 3.59) and TA (C: 4.58 – 4.45, SH: 4.58 – 4.58, UV: 4.58 – 4.42) did not vary significantly, the treatments were efficient in reducing microbe during the storage time (Pan and Zu, 2012). TSS also remained almost constant during the storage period (C: 10.43 – 12.87, SH: 10.43 – 10.60, UV: 10.43 – 11.27), indicating that the orange did not undergo rapid ripening or senescence. Pristijono et *al.* (2019) irradiated Tahitian limes with different doses (0, 3.4, 7.2, and 10.5 kJ/m$^2$) and stored at room temperature (10 °C and a relative humidity of 80 %). Similarly, TSS and TA of Tahitian limes did not change, suggesting that pre-storage treatments did not affect these quality parameters may be due to distinct responses of defense mechanism.

**Fruit length, width, and weight**

The measurements of length and width confirmed that the fruits possessed an ovoid shape. This holds significance as it enables the design of processes and equipment tailored to the morphology of the fruits. It was established that postharvest treatment, storage time, and interaction between the factors had significant effects on width, length, and weight of rangpur red lime, Tahitian lime, and sweet orange ($p < 0.05$). According to Figure 3, length and width tended to decrease during the initial days of storage. Weight loss is associated with the water loss by transpiration and respiration during ripening and senescence stages (Barreto *et al.*, 2016). Moreover, when the relative humidity falls below 90 % and the ambient temperature increases, metabolic activity intensifies, leading to greater water loss and a decline in fruit quality. At the end of the storage, rangpur red limes exhibited average weight loss percentages of 30.5 %, 39.1 %, and 44.2 % for the C, SH, and UV treatments, respectively. Tahitian lime (C: 27.4 %, SH: 34.4 %, UV: 9.6 %) and sweet orange (C: 21.9 %, SH: 11.5 %, UV: 11.3 %) presented greater average weight loss percentage without treatment because of their size. Lufu *et al.* (2020) reported that larger fruits exhibit a lower rate of moisture loss compared to smaller fruits because smaller fruits have a higher surface area to volume ratio.

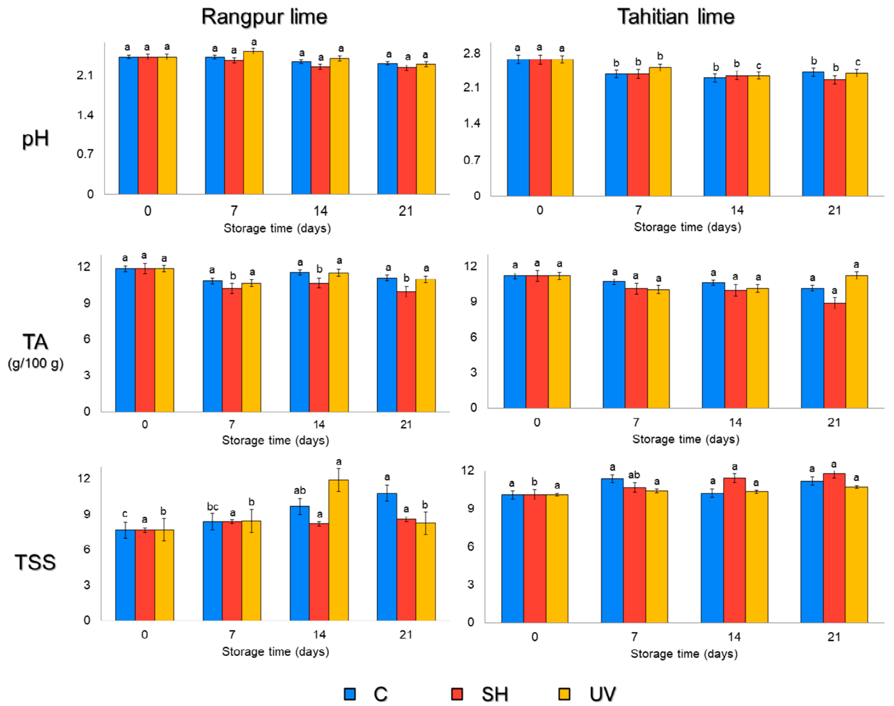


**Figure 2.** Values of pH, titratable acidity (TA), and total soluble solid (TSS) content of rangpur red lime and Tahitian lime, without treatment (C), treated with sodium hypochlorite (SH), and irradiated with ultraviolet short wave (UV) during storage at 26 °C for 12 d. Vertical lines correspond to standard error. Distinct lowercase letters (a-c) positioned above bars (separately for each treatment) denote significant disparities ($p < 0.05$).

**Figura 2.** Valores de pH, acidez titulable (TA) y contenido de sólidos solubles totales (SST) del limón mandarino y limón Tahití sin tratamiento (C), tratados con hipoclorito de sodio (SH) e irradiados con onda corta ultravioleta (UV) durante el almacenamiento a 26 °C durante 12 días. Las líneas verticales corresponden al error estándar. Las letras minúsculas distintas (a-c) dispuestas encima de las barras (por separado para cada tratamiento) denotan disparidades significativas ($p < 0.05$).

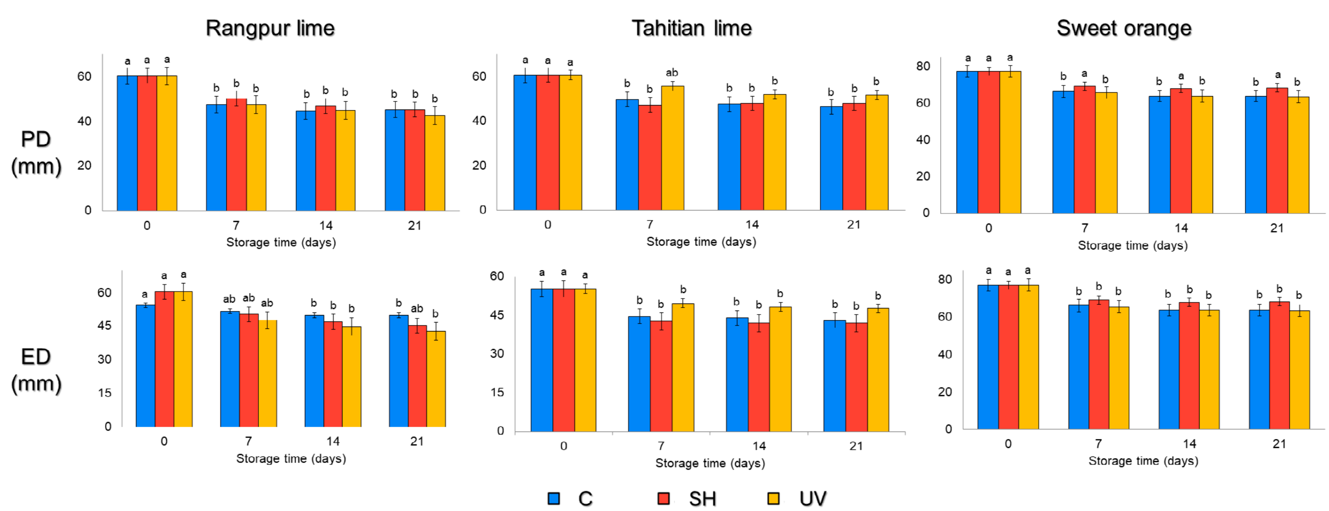


**Figure 3.** Values of polar diameter (PD) and equatorial diameter (EQ) of rangpur red lime, Tahitian lime, and sweet orange, without treatment (C), treated with sodium hypochlorite (SH), and irradiated with ultraviolet short wave (UV) during storage at 26 °C for 12 d. Vertical lines correspond to standard error. Distinct lowercase letters (a-b) positioned above bars (separately for each treatment) denote significant disparities ($p < 0.05$).

**Figura 3.** Valores del diámetro polar (PD), diámetro ecuatorial (EQ) y porcentaje de pérdida de peso (WL %) del limón mandarino, limón Tahití y de la naranja dulce sin tratamiento (C), tratados con hipoclorito de sodio (SH) e irradiados con onda corta ultravioleta (UV) durante el almacenamiento a 26 °C durante 12 d. Las líneas verticales corresponden al error estándar. Las letras minúsculas distintas (a-b) dispuestas encima de las barras (por separado para cada tratamiento) denotan disparidades significativas ($p < 0.05$).

SH and UV samples reduced weigh loss by decreasing metabolic activity and delaying respiration and transpiration rate. Pristijono *et al.* (2019) irradiated Tahitian limes with distinct doses (0, 3.4, 7.2, and 10.5 kJ/$m^2$) and observed that the highest dose resulted in the most significant reduction in weight loss (1.5 %) during storage for up to 28 d in air at 10 °C. Mandarin fruits cv. 'Ortanique' were subjected to disinfection by immersion in a 10 % sodium hypochlorite solution for 2 minutes. Although this treatment did not result in a significant reduction of weight loss, by the end of a 28-day storage period, the percentage of weight loss reached approximately 5 % (El Guilli *et al.*, 2016). Variations were attributed to differences in temperature and relative humidity. In the present study, higher temperatures, and a relative humidity of 70 % were considered. These conditions facilitated accelerated weight loss compared to the investigations referenced.

As Table 1 shows, there was a strong inverse correlation between weight loss and equatorial diameter. It suggested that weight loss primarily led to a decrease in the width of citrus fruits during storage. For rangpur red lime, a moderate and inverse correlation was observed between the percentage of weight loss and titratable acidity. This could be attributed to the decrease in titratable acidity being associated with a reduction in organic acid content during respiration (Burdon *et al.*, 2007). Concurrently, there is a release of $CO_2$ and water, contributing to weight loss. In the case of Tahitian lime, there was a moderate correlation between TA and pH, as these parameters consistently remained stable during storage. This suggests that the constancy of organic acids contributed to acidity and a low pH (Miller *et al.*, 2022). A low correlation between TA and TSS was found. As reported by Batista-Silva *et al.* (2018), during ripening of non-climacteric citrus fruits, there is a decline in titratable acidity attributed to the catabolism of citrate. Furthermore, granulation might occur as a natural process in citrus species, wherein sugar levels increase during ripening and subsequently stabilize or decrease, leading to a deterioration in the quality of citrus fruits (Johari *et al.*, 2023).

**Color parameters**

In accordance with the two-way ANOVA, it was found that postharvest treatment, storage time, and the interaction between these factors had a significant effect on all surface color parameters of rangpur red lime, Tahitian lime, and sweet orange ($p < 0.05$). The use of UV-C and NaClO enabled the increase of L* values for all citrus fruits throughout and at the end of the storage period, respectively (rangpur red lime: 45.610 – 59.391, Tahitian lime: 47.170 – 60.308, sweet orange: 59.643 – 61.366). Control samples exhibited accelerated ripening and granulation, leading to a dry appearance and a reduction in luminosity (rangpur red lime: 45.610 – 40.628, Tahitian lime: 47.170 – 37.281, sweet orange: 59.643 – 50.710). Conversely, SH treatment induced browning on the surfaces of the fruits (rangpur red lime: 45.610 – 51.468, Tahitian lime: 47.170 – 57.272, sweet orange: 59.643 – 54.049). Garzón-García et al. (2023) noted that immersing fresh-cut mango in a 10 mg/L sodium hypochlorite solution led to a reduction in L* values. This effect occurred because NaClO can act as an oxidizing agent. Consequently, UV-C treatment resulted in the inhibition of polyphenol oxidase (PPO) activity.

According to Figure 4, the results of a* coordinate showed that the rangpur red lime reached full ripeness by day 14 of storage. Subsequently, it began to exhibit a loss of red color which may be due to carotenoids oxidation and isomerization promoted by light, temperature, oxygen, and abiotic stress during storage (Rodriguez-Amaya, 2019). Nevertheless, UV-C treatment delayed significantly changes in a* coordinate compared to the other treatments by mediating the activity of some enzymes such as carotene isomerase (Sonntag et al., 2023). On the other hand, values of a* coordinate corresponding to Tahitian lime showed slightly differences during storage, but these remained in the green scale. Pristijono et al. (2019) also found that Tahitian limes irradiated with 3.4, 7.2, and 10.5 kJ/$m^2$ retained the green peel color during storage. This implied that the selected UV-C treatment delayed chlorophyll degradation and the increase in phaeophytin content. However, higher UV-C doses may

**Table 1.** Correlation coefficient between pH, titratable acidity (TA), total soluble solid (TSS), polar diameter (PD), equatorial diameter (EQ), and weight loss percentage (WL %) of rangpur red lime, Tahitian lime, and sweet orange.

**Tabla 1.** Coeficiente de correlación entre pH, acidez titulable (TA), sólidos solubles totales (SST), diámetro polar (PD), diámetro ecuatorial (EQ) y porcentaje de pérdida de peso (WL %) del limón mandarino, limón Tahití y naranja dulce.

| Correlation | Citrus fruit | | | | | |
|---|---|---|---|---|---|---|
| | Rangpur red lime | | Tahitian lime | | Sweet Orange | |
| | Coefficient | p-value | Coefficient | p-value | Coefficient | p-value |
| TA-pH | 0.317 | 0.060 | 0.538 | 0.001 | 0.308 | 0.067 |
| TA-TSS | -0.012 | 0.950 | -0.358 | 0.032 | -0.091 | 0.597 |
| WL %-TA | -0.465 | 0.004 | -0.547 | 0.001 | 0.110 | 0.522 |
| WL %-ED | -0.901 | 0.000 | -0.928 | 0.000 | -0.792 | 0.000 |
| WL %-PD | -0.879 | 0.000 | -0.801 | 0.000 | -0.649 | 0.000 |

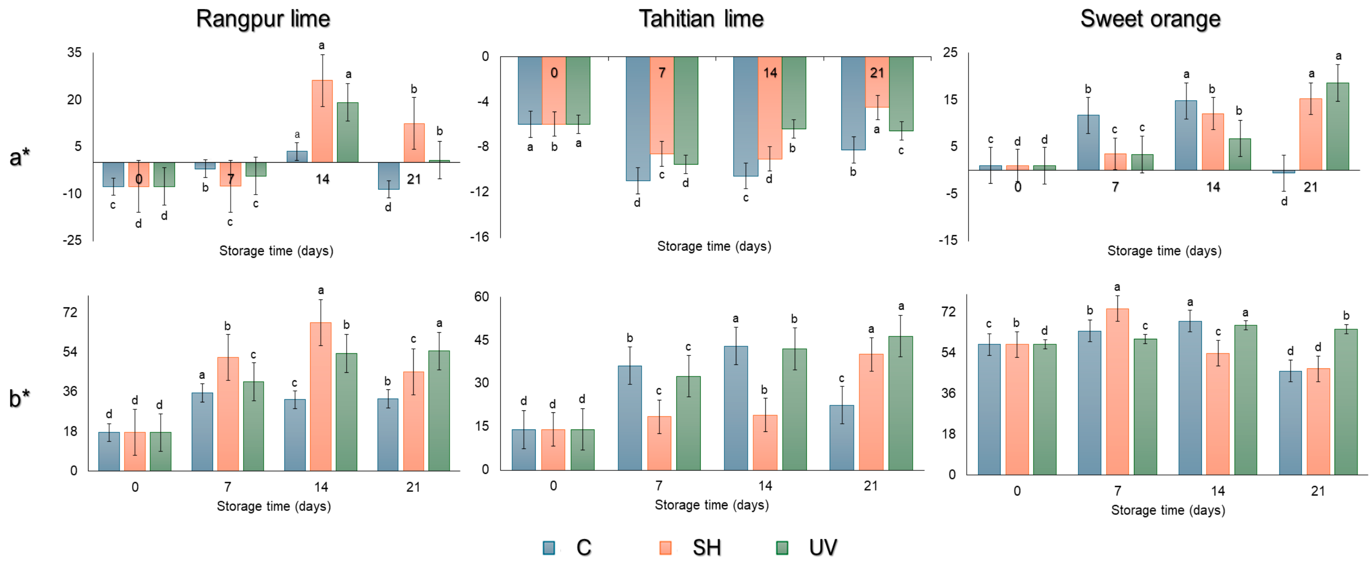


**Figure 4.** Values of a* and b* of rangpur red lime, Tahitian lime, and sweet orange, without treatment (C), treated with sodium hypochlorite (SH), and irradiated with ultraviolet short wave (UV) during storage at 26 °C for 12 d. Vertical lines correspond to standard error. Distinct lowercase letters (a-b) positioned above bars (separately for each treatment) denote significant disparities ($p < 0.05$).
**Figura 4**. Valores de las coordenadas a* y b* del limón mandarino, limón Tahití y de la naranja dulce sin tratamiento (C), tratados con hipoclorito de sodio (SH) e irradiados con onda corta ultravioleta (UV) durante el almacenamiento a 26 °C durante 12 d. Las líneas verticales corresponden al error estándar. Las letras minúsculas distintas (a-b) dispuestas encima de las barras (por separado para cada tratamiento) denotan disparidades significativas ($p < 0.05$)

lead to nonenzymatic browning and a reduction in brightness and green color (Sonntag et al., 2023). For sweet orange, sodium hypochlorite and UV-C treatments were found to regulate ripeness and inhibited browning. Untreated samples exhibited a decrease in a* values after day 14 of storage, possibly for the increment of metabolism activity and thus, the enzymes activity responsible for carotenoid degradation.

The b* coordinate also indicated the apparition of red tones and the accumulation carotenoids in citrus fruits (Lado et al., 2019), as shown in Figure 4. For rangpur red lime, untreated fruits and samples treated with NaClO showed a rapid increase in b* values until day 14 of storage. Afterward, these values tended to stabilize and decrease, respectively. Conversely, the UV-C treatment demonstrated an elicitor effect, as the values of a* increased in irradiated samples during storage. As reported by Castillejo et al. (2022), UVR8 protein is a UV-B and UV-C specific photoreceptor that interacts with COP1 and regulates HY5 gene expression, which increases the production of carotenoids for photoprotection. For Tahitian lime, the b* values of untreated samples declined after day 14 of storage, possibly due to granulation and the fruit taking on grayish hues (Sharma et al., 2006). In contrast, samples treated with sodium hypochlorite and UV-C exhibited a tendency to increase the a* coordinate until the end of the storage period. Sweet oranges showed an increase in the a* coordinate until day 14 of storage, which indicate fruit maturation. Following that, a* values for untreated samples and those treated with NaClO showed a tendency to decrease. UV-C treatment could preserve the yellow by reducing ethylene production (Lacerna et al., 2018).

In Table 2, the values of h* and YI of samples are presented with the results of two-way ANOVA and Tukey post-hoc test. The calculation of YI and h* allowed to establish that untreated samples experienced accelerated ripening at the start of storage, and granulation towards the end of the storage period, respectively. The treatments effectively prevented accelerated ripening. Nevertheless, UV-C irradiation induced uniform coloration on the citrus fruits peel, as evidenced by the rise in YI. According to Pristijono et al. (2019), the green color is a crucial factor for marketing Tahitian limes. Typically, lower hue values are exhibited during storage, accompanied by the emergence of yellow tones due to maturation.

## CONCLUSIONS

This research highlights the importance of postharvest treatment in citrus fruits before their distribution and market locally. In general, the lack of a postharvest treatment significantly promotes weight loss and accelerated ripening. The decrease in dimensions of citrus fruits, especially in terms of width, and the occurrence of granulation, contribute to a loss of quality and acceptance. It was found that the application of UV-C allowed to preserve the shelf-life of rangpur red lime, Tahitian lime, and sweet orange cv. 'Sweety' for 21 d at 26 °C and a relative humidity of 70 %, based on psychochemical, morphological, and color parameters. Further studies should focus on sensory, microbiological, and bioactive compound analyses.

**Table 2.** Hue (h*) and yellow index (YI) of rangpur red lime, Tahitian lime, and sweet orange, without treatment (C), treated with sodium hypochlorite (SH), and irradiated with ultraviolet short wave (UV) during storage at 26 °C for 12 d. Values corresponded to mean ± standard deviation. For each color parameter, means that do not share the same letter are significantly different ($p < 0.05$).

**Tabla 2.** Tono (h*) e índice de amarillamiento (YI) del limón mandarino, limón Tahití y de la naranja dulce sin tratamiento (C), tratados con hipoclorito de sodio (SH) e irradiados con onda corta ultravioleta (UV) durante el almacenamiento a 26 ° C durante 12 d. Los valores corresponden a la media ± desviación estándar. Para cada parámetro de color, las medias que no comparten la misma letra son significativamente diferentes ($p < 0,05$).

| Color parameter | Treatment | Storage time (d) | | | |
|---|---|---|---|---|---|
| | | 0 | 7 | 14 | 21 |
| *Rangpur red lime* | | | | | |
| | C | 113.367±0.081$^{a}$ | 93.048±0.026$^{e}$ | 83.764±0.005$^{g}$ | 104.408±0.003$^{b}$ |
| h* | SH | 113.367±0.081$^{a}$ | 98.224±0.000$^{c}$ | 68.808±0.002$^{j}$ | 74.547±0.008$^{h}$ |
| | UV | 113.367±0.081$^{a}$ | 95.940±0.008$^{d}$ | 70.256±0.023$^{i}$ | 89.141±0.003$^{f}$ |
| | C | 55.347±0.521$^{i}$ | 89.705±0.365$^{h}$ | 99.149±0.008$^{g}$ | 115.846±0.316$^{f}$ |
| YI | SH | 55.347±0.521$^{i}$ | 124.757±0.044$^{d}$ | 147.438±0.034$^{a}$ | 125.649±0.024$^{d}$ |
| | UV | 55.347±0.521$^{i}$ | 118.809±0.212$^{e}$ | 136.352±0.207$^{b}$ | 131.475±0.061$^{c}$ |
| *Tahitian lime* | | | | | |
| | C | 112.983±0.071$^{c}$ | 106.865±0.003$^{e}$ | 103.754±0.010$^{g}$ | 110.122±0.005$^{d}$ |
| h* | SH | 112.983±0.071$^{c}$ | 114.938±0.061$^{b}$ | 115.301±0.015$^{a}$ | 96.396±0.003$^{j}$ |
| | UV | 112.983±0.071$^{c}$ | 106.315±0.021$^{f}$ | 98.643±0.003$^{h}$ | 98.025±0.007$^{i}$ |
| | C | 42.583±0.557$^{i}$ | 112.721±0.227$^{b}$ | 119.760±0.132$^{a}$ | 86.368±0.076$^{f}$ |
| YI | SH | 42.583±0.557$^{i}$ | 82.521±0.507$^{g}$ | 76.047±0.127$^{h}$ | 111.874±0.126$^{b}$ |
| | UV | 42.583±0.557$^{i}$ | 93.932±0.048$^{e}$ | 105.209±0.039$^{d}$ | 110.107±0.060$^{c}$ |
| *Sweet orange* | | | | | |
| | C | 88.923±0.021$^{b}$ | 79.5853±0.037$^{f}$ | 77.763±0.014$^{g}$ | 90.710±0.011$^{a}$ |
| h* | SH | 88.923±0.021$^{b}$ | 87.242±0.004$^{c}$ | 77.327±0.003$^{h}$ | 72.057±0.005$^{j}$ |
| | UV | 88.923±0.021$^{b}$ | 86.714±0.010$^{d}$ | 84.132±0.006$^{e}$ | 73.885±0.002$^{i}$ |
| | C | 138.564±0.037$^{e}$ | 147.920±0.824$^{c}$ | 157.004±0.276$^{a}$ | 129.798±0.054$^{g}$ |
| YI | SH | 138.564±0.037$^{e}$ | 150.205±0.149$^{b}$ | 131.721±0.109$^{f}$ | 124.561±0.044$^{h}$ |
| | UV | 138.564±0.037$^{e}$ | 139.977±0.039$^{d}$ | 156.934±0.239$^{a}$ | 150.420±0.016$^{b}$ |

## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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