Short UV-C treatments extend the shelf-life of fresh-cut strawberries *(Fragaria x ananassa Duch cv. Camarosa)*

Extensión de la vida útil de las fresas *(Fragaria x ananassa Duch cv. Camarosa)* minimamente procesadas empleando tratamientos cortos con UV-C

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**ABSTRACT**

In recent years there has been a marked increase in the demand for fresh-cut fruit. Although these products have high user convenience, they are extremely perishable. Consequently, they must be marketed within a very short period. A number of studies have shown that brief UV-C irradiation prior to storage may reduce postharvest deterioration in whole fruit. Herein, we evaluated the influence of different UV-C dose and intensity combinations on the quality and shelf-life of fresh-cut strawberries. Fresh berries were cut in wedges and subjected to brief UV-C treatments having different combinations of radiation intensity (0, 9, or 36 W m-2) and dose (0, 2, or 4 kJ m-2). Treatments with a dosage of 4 kJ m-2 at an intensity of 36 W m-2 decreased decay, juice leakage, dehydration softening, and yeasts and mold counts. UV-C treated berries also scored better in freshness color and overall acceptability in consumer tests. The treatments did not affect the acidity, soluble solids, or phenolic compounds. Results suggest that short UV-C treatment could be useful to supplement cold storage, extending the shelf-life of fresh-cut strawberries.

Keywords: berries, irradiation, quality, postharvest

**RESUMEN**

En los últimos años ha habido un aumento en la demanda de frutas mínimamente procesadas. A pesar de ser muy convenientes en términos de su uso, estos productos son extremadamente perecederos lo que hace que deban distribuirse en un periodo muy corto. Algunos estudios han mostrado que la irradiación UV-C antes del almacenamiento puede retrasar el deterioro de frutos frescos enteros. En este trabajo se evaluó la influencia de diferentes combinaciones de dosis e intensidad de radiación UV-C en la calidad y vida útil de frutilla mínimamente procesada. Las fresas se trataron con diferentes intensidades (0, 9 o 36 W m-2) y dosis (0, 2 o 4 kJ m-2) de radiación UV-C a fin de optimizar las condiciones de exposición. Los tratamientos con una dosis de 4 kJ m-2 y una intensidad de 36 W m2 redujeron las podredumbres, el exudado de jugo, la deshidratación el ablandamiento y el recuento de mohos y levaduras. Los frutos tratados obtuvieron además mayor puntuación en frescura, color y aceptabilidad sensorial en paneles de consumidores. Los tratamientos UV-C no afectaron la acidez, sólidos solubles y fenoles totales. Los tratamientos UV-C resultan una alternativa eficaz para complementar las beneficios de la refrigeración y extender la vida útil de frutilla mínimamente procesada.

Palabras clave: fresas, irradiación, productos frescos cortados, postcosecha.


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antioxidants (Romanazzi et al., 2016). However, the effects induced by UV-C radiation are variable and largely dependent on the organ type, species, cultivar, ripening stage processing degree and irradiation conditions (Bu et al., 2013; Gayán et al., 2014 Ab- dipour et al., 2019). In strawberry treatments with UV-C doses ranging between 0.25-4.0 kJ m⁻² have been reported to improve postharvest quality maintenance (Ortíz-Araque et al., 2019). Cote et al. (2013) highlighted the importance of radiation intensity as a major factor besides to the total radiation dose applied. The relevance of considering both, the treatment dosage and radiation intensity was also highlighted in UV-B treated vegetables (Darré et al., 2017) though both process control variables rarely reported.

Some studies have reported benefits of UV exposure in fresh-cut fruits and vegetables (Graça et al., 2020). The number of studies is much more limited when compared to unprocessed commodities. This may rely on the fact that these products are normally subjected to a wet disinfection step. While this may be speculated to decrease the potential benefits of UV-C treatments, this needs to be evaluated in a commodity-dependent manner. A recent report by Li et al. (2019) showed positive results in cut strawberries treated with UV-C radiation. However, in this study the role of radiation intensity on treatment efficacy was not addressed. The aim of this work was to select the appropriate UV-C radiation dose and intensity conditions for the postharvest treatment of fresh cut strawberries and to determine their influence on fruit physical, chemical, microbiological, sensory quality.

Materials and methods
Selection of optimal UV-C radiation dose and intensity combination

Strawberries cv. Camarosa produced in greenhouses in La Plata Argentina were harvested at commercial maturity (100% red surface color) and transported to the laboratory within 1 hour. The fruit was further selected to eliminate those having physical damage ripening or shape defects, washed with chlorinated water (NaClO 100 mg L⁻¹, pH 6.5) and cut longitudinally to the main axis in quarters. After cutting the fruit, was washed again drained to eliminate water excess and subjected to the following treatments:

i. Control: Unexposed to UV-C light. ii. UV-C low intensity / low dose: Fruit treated with UV-C radiation at an intensity of 9 W m⁻² and dose of 2 kJ m⁻². iii. UV-C low intensity / high dose: Fruit treated with UV-C radiation at an intensity of 9 W m⁻² and a dose of 4 kJ m⁻². iv. UV-C high intensity / low dose: Fruit treated with UV-C radiation at intensity of 36 W m⁻² and a dose of 2 kJ m⁻². v. UV-C high intensity / high dose: Fruit treated with UV-C at an intensity of 36 W m⁻² and a dose of 4 kJ m⁻². The fruit was rotated to ensure even exposure to UV radiation. The irradiation treatments were performed in a mobile cabinet (1.7m × 0.8m × 0.5m) equipped at the top with 12 UV-C lamps (peak emission UV-C at 254 nm, TUV G30TB, 30 W, Philips, Argentina). The distance between the emitting source and the fruit was in all cases 30 cm. The dose was established by varying the treatment times and intensity by modifying the number of lamps on. The UV-C radiation dose was evaluated using a digital UV-C radiometer (Electro Lite LC 300, United States) located in the center of the irradiation cabinet. After the treatments, the fruits were placed in polyethylene terphthalate trays (10 × 15 × 3 cm) with perforated lids (1 perforation of 1 mm diameter per cm⁻²). Forty fruit wedges were placed per tray. Four separate trays were analyzed for each treatment and the whole experiment was performed in duplicate. After 4 days of storage at 4 °C fruit was evaluated for decay incidence to select the optimal treatment condition.

Effect of selected UV-C treatment fruit physic-chemical, microbiological, and sensory quality and shelf-life

Strawberries cv. Camarosa were harvested, selected, disinfected, and processed as described in the previous section. The berries were subsequently subjected to UV-C irradiation (intensity 36 W m⁻², dose 4 kJ m⁻²) and packed in polyethylene terephthalate trays with perforated lid (one of 1-mm diameter perforation per cm²). Forty fruit wedges were placed per tray. Fruit was stored at 4 °C for 7 days. Corresponding controls without UV-C treatment were packaged and stored as described above. At different storage times (0, 4 and 7 days) samples were taken and used for quality evaluation. For chemical analyses samples were frozen in liquid nitrogen and stored at -80 °C until use. Three trays were done per treatment and storage time and the whole experiment was done in duplicate.

Visual Deterioration Index and juice exudate: A Visual Deterioration Index (VDI) was calculated using a hedonic five-point scale (being 1: no visual damage and 5: serious damage). The attributes evaluated for VDI were the presence of rot and macerated areas as well as the loss of surface brightness. Exudate juices were determined by weighing the liquid released on each individual tray along storage. Results were expressed in gram per kilogram on fresh weight basis. Six measurements were made for each treatment and storage time.

Weight loss: The individual trays were weighed throughout the storage period. Weight loss was calculated according to the following equation: Weight loss (%) = 100 × (Pi-Pf) / Pi, with Pi and Pf being the initial weight and the weight at each storage time respectively. Six measurements were made for each treatment and storage time.

Yeasts and molds plate counts: 50 g of fruit wedges were put in pre-sterilized beakers containing 225 ml of 0.1% w/v peptone. The samples were shaken for 15 min and two series of dilutions (10⁻²-10⁻¹) of the washing liquid were prepared. One milliliter of each dilution was loaded in Petri dishes with YGC medium and incubated at 20 °C for 5 days. The plates showing between 30 and 300 colonies were counted and the results were expressed as log of colony forming units (CFU) per gram of fresh fruit.

Firmness: Fruit firmness was determined by uniaxial puncture tests on a Texture Analyzer (TA.XT2, Stable Micro Systems Texture Technologies, NY, United States) equipped with a 3 mm diameter flat probe. Samples were compressed 2 mm at a speed of 0.5 mm s⁻¹. The initial slope of the fruit distance curve was calculated. Results were expressed in N mm⁻¹. Sixty measurements were done for each treatment and storage time.

Surface color: Measurements were done with a chromameter (Minolta CR-400, Japan equipped with the CIE C illuminant and with a viewing angle of 0°, to determine the L°, a° and b° values. Fruit hue (tg⁰b° / a°) and chroma (a° + b°)²/2 were calculated. Thirty measurements were made for each treatment and storage time.

pH, acidity, and soluble solids: Fruit wedges were ground in a mill and 5 g of the resulting sample were taken to 100 mL with water. The initial pH was measured using a pH meter and the sample was titrated with 0.1 M NaOH to pH 8.2 determined potentiometrically (AOAC, 1980). Results were expressed as mmol H⁺ kg⁻¹ on fresh weight basis. For soluble solid (SS) measurement ground tissue was filter through a cloth and measured in a self-compensated digital refractometer (HI 96801, Argentina). Results were expressed in % w/w. Six measurements were done for each treatment and storage time.
**Phenolic content**: Fruit phenolic content representing the most abundant group in berries (Martinsen et al., 2020) was determined spectrophotometrically in ethanolic extracts according to Singleton et al. (1995). Results were calculated by using chlorogenic acid (CGA) as a standard. Results were expressed as mg CGA equivalents per kilogram on fresh weight basis. Three extracts were analyzed for each treatment and storage time.

**Sensory evaluation**: A consumers sensory acceptability test was conducted for control and UV-C treated fruit stored at 4 °C for 7 d. The panel consisted of 50 consumers with an equal proportion of men and women and an age range of 25-35 years old. The panelists were asked to score the fruit in a 9-point hedonic scale (1: poor, 9: excellent) for the following attributes: i) freshness, ii) color and iv) overall acceptability.

**Statistical analysis**: The experiments were performed according to a factorial design, being the factors the treatment (experiments 1 and 2) and storage time (experiment 2). Data was analyzed by means of an ANOVA using the InfoStat software, version 2018 Córdoba, Argentina (Di Renzo et al., 2018). The model assumptions of homogeneity of variance and normality were tested by means of the Levene and Shapiro–Wilk tests, respectively and the means were compared with the Fisher test at a significance level of P < 0.05.

**Results**

**Selection of optimal UV-C radiation dose and intensity combination**

Berries are among the most perishable fruit (Pott et al., 2019). Their high metabolic and softening rates and decay susceptibility normally lead to a very brief postharvest life even under proper refrigeration (Panou et al., 2020; Muley and Singhal, 2020). In the first experiment the main cause of fruit deterioration during storage was the formation of discrete macerated areas within the fruit surface. This was accompanied in severely rotten fruit by fungal mycelia signs. All four UV-C treatments evaluated significantly reduced the fruit decay relative to the control (Fig. 1). The use of UV-C treatments for disease control has already been reported in whole strawberry with doses ranging between 0.25 and 4.00 kJ m⁻² (Nigro et al., 2000, and Pan et al., 2004). In fresh-cut berries a single recent study has been conducted with positive effects in terms of decay control in fruit subjected to a UV dose similar to that tested herein (Li et al., 2019). However, in this study the influence of different radiations intensities, for as similar dose, were not evaluated. In the present work, the UV-C treatments at the lowest dose already controlled rot incidence. Under this UV-C dosage no impact of the irradiance used was found in terms of treatment efficacy. Contrariwise, differences in decay control were found between UV-C doses when high radiation intensity was applied. The UV-C treatment combining high intensity and high dosage (36 W m⁻² and 4 kJ m⁻²) turned out to be the most effective condition for decay control. Cote et al. (2013) in strawberry reported that the high UV-C radiation intensity improves decay control though this work was done in unprocessed, less mature, and unwashed berries. Moreover, these authors did not assess the influence of different dose-intensity combinations. Based on the results obtained, the high dose-high intensity UV-C treatment (4 kJ m⁻² - 36 W m⁻²) was selected to further characterize the impact on fruit physico-chemical, microbiological, sensory properties during storage.

**Effect of selected UV-C treatment fruit physic-chemical, microbiological, and sensory quality and shelf-life**

The most prevalent deterioration symptoms during storage were loss of surface brightness and formation of rotten areas. Strikingly, tissue decay was most common in the outer zone of the receptacle (pigmented sides) than in the radial (white, pink) cutting region. This differs from what has been reported in other fresh-cut products, in which the cutting zones become the most susceptible areas (Rodoni et al., 2017). One plausible and simple explanation could be that the internal radial fruit region still contains unripe tissues, and that the protective effect of this maturity factor on decay susceptibility is more relevant that caused by the removal of natural barriers through cutting. Besides this control and UV-C treated fruit showed clear differences in terms of the Visual Deterioration Index (VDI). After 4 days of storage, the VDI was already significantly lower in UV-C irradiated fruit (Fig. 2).
are relevant for very perishable commodities such as fresh-cut strawberry which rarely lasts more than 7 d.

Another clear difference found between control and UV-C treated fruit was the exudates of fruit juices, after 7 d of storage and indirectly indicating greater cell rupture control fruits released 20 times more juices in the trays than the corresponding UV-C treated berries (Fig. 3).

To understand whether the responses in this case were due to a germicide response we tested the changes in fungal CFU in control and treated fruit immediately after UV exposure as well as along storage. The main fungi that have been associated strawberry postharvest decay include Botrytis and Rhizopus (Nigro et al., 2000; Agyare et al., 2020). Yeasts have been also reported to cause soft rots in fresh-cut commodities (Graça et al., 2020). Immediately after irradiation no changes in yeast and mold counts were found (Fig. 4).

UV-C treated fruit showed lower weight loss than the control at the end of storage (Fig. 5). Lamickanra et al. (2005) suggested that irradiation of fresh-cut Galia melon partially dehydrated the fruit epidermis and then prevented subsequent water loss. Rodoni et al. (2012) suggested that UV exposure by favoring the cross-linking of wall proteinaceous and phenolic components may increase fruit resistance to dehydration. Although further studies would be necessary to establish the mechanisms involved, results show that the UV-C treatments applied herein were beneficial also by preventing tissue dehydration.

To determine if exposure to UV radiation caused modifications in other relevant quality attributes, the impact on color, acidity, soluble solids content and phenolic content was determined (Table 1). Overall color changes along storage were slight since it started with fruits in a state of advanced maturity. However, on the last day of sampling, treated fruit showed higher lightness (L*) and hue angle, pointing to a delay in surface reddening. Fruit pH, acidity, soluble solids content showed not major variation throughout storage or as in response to UV-C exposure. This is in line with the results reported in the literature (Cote et al., 2013; NimithKeat-kai and Kulthip, 2016; Safiri et al., 2015). Finally, when analyzing...
the content of total phenolic compounds an increasing trend was found with storage. Regarding the impact of UV-C, after 4 days, no differences were observed between control and treated fruit. At the last day of sampling UV-C treated fruit showed a slight delay in phenolic compounds accumulation. This differs from previous work in which the use of UV-C radiation elicited antioxidant compounds (Li et al., 2019; Esu et al., 2019; Duarte-Sierra et al., 2019; Michailidis et al., 2019). The present results show that the inductive effect of UV-C of phenolic compound biosynthesis is highly dependent on the irradiation conditions and likely in the product processing stage as well. The reduction in phenolic content found at the last sampling point is of little relevance from an antioxidant intake point of view, if any.

Table 1. Lightness (L°), Hue, pH, acidity, SS and phenolic content control or UV-C treated (radiation intensity 36 W m⁻² and radiation dose 4 kJ m⁻²) fresh-cut strawberry, stored at 4 °C for 7 days. Different letters indicate significant differences according to Fisher’s test with a significance level of P < 0.05.

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<td>UV-C</td>
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<td>UV-C</td>
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<td>UV-C</td>
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Source: Authors

We finally conducted as consumer sensory test for three relevant attributes for fruit purchase (freshness, color, and overall acceptability). UV-C treated berries showed regardless of the attribute higher scores than the control.

Conclusions

In this work we first selected a proper combination of radiation dose and intensity for postharvest treatment of fresh cut strawberry. Treatments at the highest dose (4 kJ m⁻²) and intensity (36 W m⁻²) showed the greatest benefits in terms of fruit decay control and shelf-life extension. UV-C treated berries showed reduced deterioration, juice exudates, weight loss, softening, yeasts and mold counts and presented higher scores in consumer sensory tests. The treatments did not cause major changes in fruit pH, acidity soluble solids or phenolic compounds. UV-C treated berries after one week, a similar deterioration than control fruit upon 4 days. Taken together results suggest that short UV-C treatment could be useful to supplement cold storage, extending the shelf-life of fresh-cut strawberries.

References


Short UV-C treatments extend the shelf-life of fresh-cut strawberries


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