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UV-C irradiation of 'Maradol' papaya fruits: effect on physicochemical qualities and sensory characteristics

UV-C-Bestrahlung von Maradol-Papaya-Früchten; Auswirkung auf physikalisch-chemische Eigenschaften und sensorische Eigenschaften

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Summary

UV-C energy is used as a postharvest processing technology in fresh produce. It can reduce the presence of pathogenic microorganisms and increase the shelf life of produce. However, there is scarce information about the effect of this technology on the sensory characteristics of fruits. The impact of UV-C irradiation at the energy of 2.88 and 5.76 kJ/m^2 on the sensory characteristics and antioxidant capacity of 'Maradol' papaya (*Carica papaya* L.) fruits were investigated. Fruits treated with UV-C at doses of 5.76 kJ/m^2 showed a significant increase in total polyphenol content (2.16 mg gallic acid equivalent/g), lower weight loss (10.32%), and a higher score of sensory descriptors (sweetness and chewiness) compared to those of the other treatments. UV-C irradiation at a dose of 2.88 kJ/m^2 increased the antioxidant capacity (5.16 μmol trolox equivalent/g) of the fruits. Both UV-C doses increased the polyphenol content, antioxidant capacity and sensory characteristics of the fruits.

Keywords: Antioxidant capacity, DPPH, total polyphenols, postharvest technology, trained panelists

Introduction

Papaya (*Carica papaya* L.) is currently in high global consumption demand as raw, fresh or processed products (Pan et al., 2017). This fruit has acquired relevance in recent years due to its sensory properties, nutritional value and antioxidant content (Gayosso et al., 2010). The major papaya producers and exporters are India, Brazil, Nigeria and Mexico (FAO, 2017), which export over 146,000 tons annually to the US market. There is also an important local trade for Maradol papaya. However, papaya fruits are highly perishable, susceptible to diseases, undergo inadequate postharvest management (harvest, transportation and storage) and are exposed to pollutants. These affect the nutritional properties and quality attributes of the fruit (Pan et al., 2017). Firmness, weight loss and fungal deterioration are postharvest problems that affect papaya quality (Monzón-Ortega et al., 2018). Therefore, preservation systems are used to minimize nutritional losses, add value, ensure safety, increase shelf life and minimize changes in sensory characteristics (Padmanaban et al., 2014). Cold storage is the most commonly used technology. However, it is expensive for small producers, and it can cause chilling injuries (Pan et al., 2017). Another technique that is often used mainly in the export of papayas is the application of synthetic fungicides. There are several commercial products that are applied after cutting and during postharvest ripening, such as azoxystrobin, benomyl, captan, chlorothalonil, imazalil, kresoxim methyl, prochloraz and thiabendazole. However, one of the most used fungicide (due to its low cost) in the field disinfection stage of fruits is Mancozeb® (Santamaría-Basulto et al., 2011). It is also known that overexposure to synthetic fungicides can cause resistance problems in pathogens, in addition to bioaccumulation in humans, animals and the environment (Vázquez-Ovando et al., 2018).

Some authors propose the use of ultraviolet (UV) light as an alternative process in postharvest handling (Hyldgaard et al., 2012; Poubol et al., 2015; Ribeiro et al., 2012). The use of shortwave UV-C light (200–280 nm) has shown germicidal effects (including an antifungal effect), delays ripening and increases shelf life (Gutiérrez et al., 2018; Vázquez-Ovando et al., 2018). In addition, it has been reported that cabbage irradiated with 0.6 and 1.2 J/cm^2 UV-C illumination as a microbicidal treatment had a higher phenolic content and antioxidant capacity than those of untreated samples (Ruiz-López et al., 2010). However, the doses used by the authors did not modify the sensory characteristics of the vegetables. Other works have reported on UV-C illumination, as it can increase antioxidant phenolic compounds in fresh-cut carrots (Formica-Oliveira et al., 2017) and fresh-cut carambola (Moreno et al., 2017). Therefore, it is important to evaluate whether changes in these biomolecules negatively affect the sensory properties of the fruits or vegetables.

Considering that sensorial characteristics are key in the acceptance of fruit, especially those of 'Maradol' papaya, there are no reports on the effect of UV-C energy on the antioxidant capacity and sensory properties of papaya. The objective of this research was to evaluate the sensory characteristics and antioxidant capacity of 'Maradol' papaya treated with UV-C irradiation stored at room temperature.

Materials and methods

Fruits and treatments

'Maradol' papaya fruits were obtained directly from the Agro-Pacífico, SA de CV orchard (Chiapas, Mexico) located at the coordinates 14° 54' 37.8" N, 92° 20' 13.3" W. A total of 144 fruits, which were similar in size (852±37 g) and free of damage and decay, were selected at the mature green stage. They were washed with tap water and aseptically immersed in a 200 ppm sodium hypochlorite solution for 5 min. Under a completely randomized design, the fruits were classified into 4 groups (36 fruits each). A group of fruits were submitted to one of the following treatments: control (untreated); positive control (synthetic fungicide treatment, Mancozeb®); and two antifungal methods (UV-C irradiation at 2.88 kJ/m^2 and 5.76 kJ/m^2).

For synthetic fungicide treatment, the fruits were dipped in a 6 g/L Mancozeb® solution. For UV-C irradiation (λ=254 nm) treatments, 5 fruits in each group were placed on a stainless-steel surface and aligned parallel and 10 cm away from the horizontal (436 mm length) UV-C light source (two germicidal unfiltered emitting lamps, Sankyo Denki Model G15T8 15 W). The UV-C lamps were stabilized by turning them on for 30 min before use. UV-C intensity was measured by a photoradiometer (Delta Ohm LP9021 UVC, Padova, Italy), which was measured as 0.97 kJ/m^2 after an exposure time of 3 min following the protocol standardized by Pinheiro et al. (2016). The exposure times were set to achieve the UV-C illumination treatment doses of 2.88 kJ/m^2 and 5.76 kJ/m^2. During the exposure time, the fruits were turned four times to achieve homogeneous exposure at 25 ºC.

Storage and sampling

After application of the treatments, all fruits were randomly stored and distributed on pallets in a room at 30±2 °C and 80±5% relative humidity (RH) for 9 days. The fruits were measured for weight loss and peel color after treatment and every 24 h. Fruit firmness, total soluble solids content, titratable acidity, reducing sugar content, antioxidant capacity, total polyphenol content and sensory properties were evaluated after 9 days of storage, once full ripening was achieved.

Fruit analysis

Physiological parameters of the fruits were evaluated, following the procedure reported by Monzón-Ortega et al. (2018). Weight loss was monitored with an Adventurer™ Pro digital scale (Model AV264C) based on the initial weight and final weight of fruits at the time of measurement (% WL). The external color and the firmness of the fruit were recorded at the apical, middle and peduncular areas. The *L**, *a** and *b** values of the CIE Lab scale were recorded with a MiniScan EZ colorimeter (Model 4000S). Firmness was measured with a Tr® Italy penetrometer (Model 53205) equipped with an 8 mm diameter tip. The results were expressed in Newtons (N). The percentage of the total soluble solids content (TSS) was quantified with an ATAGO digital refractometer (PAL-α model). The titratable acidity content (% citric acid) was determined by AOAC Official Method 942.15 (AOAC, 2010). The reducing sugar content was measured using a dinitrosalicylic acid reagent as described by Miller (1959); the results were expressed in mg/100 g of pulp, and glucose was used as a standard.

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Polyphenol content

A total of 100 mg of papaya pulp was macerated in 1 ml of 80% v/v methanol and subsequently stirred at 200 rpm for 24 h at room temperature. The suspension was centrifuged at 2,626 g for 25 min. The supernatant was recovered and stored at –25 °C. The precipitate was subjected to a second extraction as previously described. Both methanolic extracts were combined and stored at –25 °C until use to quantify the phenolic compounds. The determination of polyphenols was performed by the colorimetric Folin-Ciocalteu method as described by Septembre-Malaterre et al. (2016). A calibration curve was performed using gallic acid as a standard. The results were expressed as mg gallic acid equivalents (GAE) per g of pulp (mg GAE/g).

Antioxidant capacity determination by the DPPH method

Papaya pulp (100 mg) was collected and macerated in 1 ml of a methanol-acetic acid-water (64:2:34) solution. Samples were homogenized on a rotary shaker (200 rpm) for 24 h at room temperature. The suspension was centrifuged at 2,626 g for 25 min. The supernatant was separated and stored at –25 °C. The precipitate was extracted again as previously described. Both extracts were combined, stored at –25 °C (Brand-Williams et al., 1995) and then used to estimate the antioxidant capacity. The DPPH (2,2-diphenyl-1-picrylhydrazyl) assay was carried out according to the method of Thaipong et al. (2006), with some modifications. An amount of 2.5 mg of DPPH in 100 ml of methanol was used as a standard. The solution was adjusted to 1.0 ± 0.02 absorbance units at 515 nm. The calibration curve was established using 20 µl Trolox solution (0–600 µM in 80% methanol) and 280 µl DPPH stock solution. The homogenized mixture was kept in the dark for 30 min. A calibration blank (80% methanol) was used. Absorbances at 490 nm were read in a microplate reader (Mindray MR-96A, Shenzhen Mindray Biomedical Electronics, China). Antioxidant capacity was measured using 20 µl extract and 280 µl of the DPPH radical. The results were expressed as antioxidant capacity in Trolox equivalents per gram of papaya pulp (µmol TE/g).

Sensory evaluation

The sensory characteristics of the fruits were evaluated with a trained panel of judges. The judges were selected and trained in descriptive methods (Lawless and Heymann, 2010). The panelist and attribute data were analyzed by variance and eleven panelists (eight men and three women), which were chosen based on their discriminative capacity (<0.30) and repeatability (>0.05), as suggested by Melo et al. (2009).

Sensory evaluation was performed in a single session in a large and closed room with adequate lighting at room temperature (25 °C). Taste descriptors (sweetness, sourness, astringency, and bitterness) and texture were judged independently. A 1 cm^3 volume of 10 pieces of papaya pulp was administered to each judge in three-digit-coded plastic circular plates. Panelists rinsed their mouths with water between samples and used unsalted biscuits to desaturate the taste. For the odor test, 1 cm^3 pulp samples in a series of five containers were presented randomly in front of the panelists. Each judge was asked to remove the lid from the sealed container, inhale the volatile substances, and record scores on a linear unstructured scale of 15 cm (transformed to a score max. of 7). All procedures were carried out in triplicate using codes of three different digits (45 different combinations) per sample and repetition. Panelists had 10 min breaks between tests.

Data analysis

All data were subjected to analysis of variance and a comparison of means with Tukey's test (alpha= 0.05). Multivariate statistics were used to find associations between variables and treatments as well as to group similar treatments. Additionally, with the data of all the variables evaluated after ripening, principal component analysis (PCA) and cluster analysis were performed. A dendrogram based on Euclidean distance dissimilarity, using the Ward agglomeration method, was constructed. For the analysis, Infostat Professional © v2015 and XLSTAT © v2012 software were used.

Results and discussion

Physiological parameters of papaya fruits

The use of UV-C energy as an alternative to obtain safe products, longer shelf life, and adequate sensory and nutritional qualities showed diverse results. In this research, the use of UV-C illumination was able to reduce the weight loss (WL) of papaya fruits stored under ambient conditions of the humid tropic (30 ± 2 ºC; 80 ± 5% RH) by the end of storage (Fig. 1). A significant difference in WL was found on the 3rd day of storage. At the end of storage, fruits treated with UV-C at 5.76 kJ/m^2 had the lowest WL (10.32%) compared to that of the other treatments. The synthetic fungicide, UV-C 2.88 kJ/m^2, and the control treatments presented WL values of 14.03, 13.17 and 13.16%, respectively. The application of UV-C energy (6.6 kJ/m^2) in mangoes resulted in decreased weight loss (Promyou and Supapvanich, 2016). It is possible that the radiation of UV-C at 5.76 kJ/m^2 could modify the respiration of papaya fruits, which decreased the transpiration rate as reported in tomato fruit irradiated with UV-C at 4.83 kJ/m^2 (Pinheiro et al., 2015).

On the initial day of storage, the peel color of fruits showed variations depending on the treatment (Tab. 1). Untreated fruits (control) showed the highest values of *L**

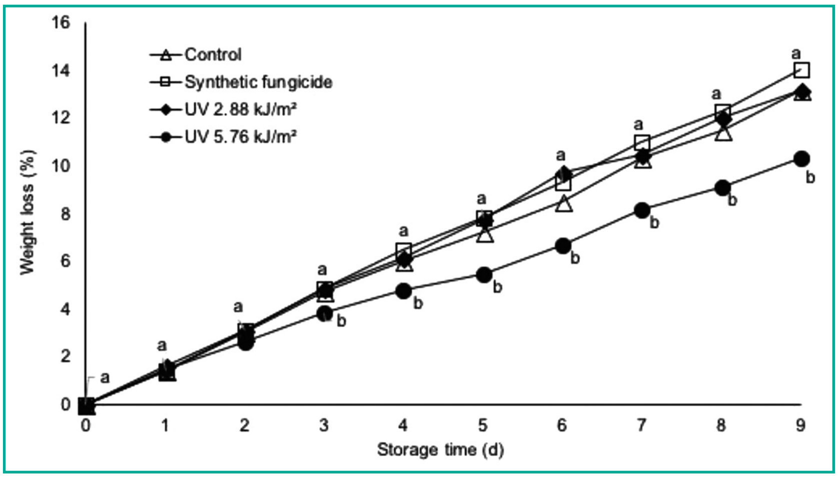

FIGURE 1: *Weight loss of 'Maradol' papaya treated with a synthetic fungicide or UV-C irradiation prior to storage at 30 °C ± 2 °C and 80 ± 5 % RH for 9 days. The data are the mean values of ten determinations. Different letters by day denote significant differences (<0.05).*

TABLE 1: *Peel color parameters; brightness (L*), green-red tone angle (a*) and blue-yellow tone angle (b*) of 'Maradol' papaya fruits treated with a synthetic fungicide or UV-C irradiation prior to storage at 30 °C ± 2 °C and 80±5% RH for 9 days.*

Treatments	Storage time (days) 0	1	2	3	4	5	6	7	8	9
					L value*					
Control	40.81^{a}	41.08^{a}	43.69^{a}	43.84^{bc}	49.73^{c}	48.98^{bc}	46.94^{cd}	44.86^{a}	54.85^{b}	56.10^{b}
Synthetic fungicide	40.48^{a}	40.21^{a}	41.46^{ab}	43.91^{bc}	43.25^{abc}	48.28^{bc}	47.60^{d}	43.61^{a}	47.07^{a}	49.56^{b}
UV-C 2.88 kJ/m^2	40.05^{a}	39.97^{a}	43.49^{a}	45.30^{c}	45.85^{bc}	49.31^{bc}	41.39^{ab}	45.23^{a}	45.68^{ab}	46.78^{a}
UV-C 5.76 kJ/m^2	40.05^{a}	40.02^{a}	41.49^{ab}	43.14^{abc}	44.73^{bc}	50.58^{c}	46.23^{bcd}	45.05^{a}	47.07^{a}	47.38^{a}
					a value*					
Control	−7.00^{a}	−6.92^{ab}	−5.09^{a}	−5.5^{ab}	−1.38^{c}	2.51^{b}	−1.09^{a}	4.98^{b}	4.46^{a}	6.97^{ab}
Synthetic fungicide	−7.04^{a}	−6.41^{ab}	−6.23^{a}	−5.12^{b}	−2.39^{abc}	1.28^{ab}	−0.77^{a}	3.62^{ab}	6.14^{a}	7.68^{b}
UV-C 2.88 kJ/m^2	−6.62^{a}	−6.07^{b}	−6.00^{a}	−5.88^{ab}	−0.02^{bc}	2.05^{b}	−0.44^{a}	3.73^{b}	6.13^{a}	6.26^{ab}
UV-C 5.76 kJ/m^2	−6.62^{a}	−6.59^{ab}	−6.79^{a}	−6.38^{ab}	−1.98^{abc}	3.18^{b}	−0.47^{a}	3.28^{ab}	4.58^{a}	3.68^{a}
					b value*					
Control	16.89^{ab}	16.32^{a}	21.65^{ab}	23.06^{a}	35.75^{b}	34.35^{b}	32.42^{b}	38.06^{b}	40.00^{a}	43.12^{a}
Synthetic fungicide	16.46^{a}	16.58^{a}	17.12^{a}	21.05^{a}	22.69^{a}	28.49^{ab}	31.33^{ab}	35.23^{b}	40.64^{a}	44.33^{a}
UV-C 2.88 kJ/m^2	18.95^{ab}	19.68^{ab}	24.37^{b}	23.16^{a}	28.55^{ab}	34.82^{b}	32.73^{ab}	37.11^{b}	40.72^{a}	44.66^{a}
UV-C 5.76 kJ/m^2	18.95^{ab}	19.42^{ab}	19.65^{ab}	21.41^{a}	25.27^{ab}	35.83^{b}	29.98^{b}	36.79^{b}	40.55^{a}	44.49^{a}

The data represent the mean values of ten determinations. Values with the same letter within a column are not significantly different (Tukey's test, >0.05).

TABLE 2: *Firmness, total soluble solids, titratable acidity, reducing sugars, total polyphenols and antioxidant capacity of 'Maradol' papaya fruits treated with a synthetic fungicide or UV-C irradiation prior to storage for 9 days at 30 °C ± 2 °C and 80 ± 5% RH.*

Treatments	Firmness (N)	Total soluble solids (%)	Titratable acidity (% citric acid)	Reducing sugars (mg 100/g)	Total polyphenols (mg GAE/g)	Antioxidant capacity (µmol TE/g)
Control	62.9±16.0^{a}	5.55±1.2^{a}	0.0018±0.001^{a}	118.22±24.9^{a}	0.642±0.091^{c}	0.31±0.12^{b}
Synthetic fungicide	56.4±14.2^{a}	6.39±1.1^{a}	0.0024±0.001^{a}	118.81±32.7^{a}	1.744±0.373^{b}	0.55±0.41^{b}
UV-C 2.88 kJ/m^2	66.2±22.1^{a}	5.59±1.4^{a}	0.0021±0.001^{a}	211.29±34.1^{b}	1.955±0.623^{b}	5.16±3.72^{a}
UV-C 5.76 kJ/m^2	66.3±30.1^{a}	5.90±1.1^{a}	0.0019±0.000^{a}	212.65±107.9^{b}	2.155±0.058^{a}	0.95±0.56^{b}

The values are the means ± standard deviations of ten determinations. Values with the same letter within a column are not significantly different (Tukey's test, >0.05). GAE= gallic acid equivalents; TE= trolox equivalents.

at the end of storage, whereas the fruits treated with synthetic fungicide showed the highest *a** values. In contrast, the fruits treated with UV-C at 5.76 kJ m^{-2} showed the lowest *L** and *a** values. The increase of *L** and *a** values indicated color changes from yellow to orange tones during fruit ripening. However, the fruits irradiated with UV-C light did not present drastic changes with *L**, *a** and *b** values with respect to their nonirradiated counterparts from the 5th day of storage. These fruits presented slight browning on the peel surface (imperceptible even in the *L** value). This change may be because the doses used in this study could have induced stressed in the fruit, and, consequently, the activity of the polyphenol oxidase enzyme (PPO) was affected, increasing the polymerization of phenolic compounds into compounds, such as quinones and other types, which agrees with the increased content of polyphenolic compounds in the fruits of the irradiated treatment groups (Tab. 2). Fruit browning has been reported to occur in 'Golden' papaya treated with a dose from 0.2 to 2.4 kJ/m^2 of UV-C (Cia et al., 2007).

The reducing sugar (RS) content in papaya fruits showed a significant difference (<0.05) between that of the control and that of the UV-C treatments. Fruits treated with UV-C illumination showed higher values of RS when compared to that of the control and synthetic fungicide treatments (Tab. 2), whereas firmness, total soluble solids (TSS) and titratable acidity (TA) were not significantly different (>0.05) between treatments. These results may indicate that UV-C irradiation did not produce negative changes or decrease enzymatic activity related to firmness maintenance and organic acid production. This coincides with what was reported by Safitri et al. (2015), who did not find significant differences in TSS and TA contents between unirradiated and irradiated Nam Dok Mai Si Thong with 4.93 kJ/m^2 of UV-C energy. In contrast, other reports show differences in fruits treated with UV-C irradiation. Kulkarni and Karadbhajne (2015) reported that the TSS content slightly increased in fresh-cut papaya fruits irradiated with UV-C energy (dose not reported) for 20 min. Yoplac et al. (2013) reported that the RS content in arugula leaves *(Eruca sativa)* treated with 15 kJ/m^2 UV-C slightly increased. It has also been reported that the reducing sugar content of pineapples treated with 4.5 kJ/m^2 of UV-C was significantly higher than that of the untreated samples (Pan and Zu, 2012). This could be explained by the fact that UV-C energy affects polysaccharide degradation pathways, which causes a slight increase in the RS content.

The content of total polyphenols and antioxidant capacity

Tab. 2 shows the total polyphenol content and antioxidant capacity (AC) in the fruit pulp. For their beneficial contribution to the health of consumers, the phenolic compounds that contribute to the antioxidant capacity of fruits are highly appreciated. The total polyphenol content in the control treatment was the lowest, with significant differences (<0.05) observed among the antioxidant capacities

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of the treatments. The other treatments presented up to three times the total polyphenol content of untreated fruits. The highest total polyphenol content was found in the samples treated with UV-C at 5.76 kJ/m². The fruit pulp treated with UV-C 2.88 kJ/m² showed a significant difference (<0.05) in AC, which was five times higher than that of the other treatments (Tab. 2). The use of UV-C energy positively modified the content of total polyphenols and AC (Tab. 2). The effect of UV-C irradiation on the accumulation of phenolic compounds has been described in various fruits and vegetables, such as strawberries (Xie et al., 2014), cranberries (Grace et al., 2014), grapes (Sheng et al., 2018), and tomatoes (Bravo et al., 2013), and has been shown to cause both dramatic and moderate increases in polyphenol content. The increase in the content of polyphenols may be due to the activation of protection mechanisms of plant tissues in response to irradiation (Ruiz-Lopez et al., 2010). It has been reported that the average content of polyphenolic compounds in ripe papaya pulp was 0.88 mg GAE/g (Gayosso et al., 2010), as was found in our results. UV-C irradiation has been reported to increase total polyphenols and AC in the peel and pulp of papaya fruit during ripening (Rivera-Pastrana et al., 2014). Our results are comparable and provide an indication that the application of UV-C irradiation stimulated polyphenol production as a defense response against oxidative stress. The dynamics of polyphenols in irradiated fruits were influenced by the doses used. It was observed that the synthetic fungicide applied to the fruits produced stress that was countered with the higher production of polyphenol content than was measured in the control treatment (Tab. 2).

The antioxidant capacity of the pulp extracts did not show the expected relationship with polyphenolic content since the lowest UV-C irradiation dose (2.88 kJ/m²) had the highest antioxidant capacity (5.16 µmol TE/g), which was higher than that of the fruits irradiated with the highest dose of UV-C. An increase in AC has been demonstrated in tomato fruits treated with UV-C at doses of 4 and 8 kJ/m² (Liu et al., 2012). This may be because polyphenol was not responsible for AC in 'Maradol' papaya, as it occurs in many living tissues. In papaya pulp, the AC that is induced by UV-C light has been linked to the catalase enzyme (CAT) and other antioxidants (Rivera-Pastrana et al., 2014). Another possible explanation may be that UV-C irradiation at the dose of 2.88 kJ/m² promoted high amounts of AC compound synthesis, similar to the content of polyphenolic compounds when treated with the highest irradiation dose, which can be attributed to ferulic acid, quercetin and/or manghaslin (Nieto-Calvache et al., 2016). Our results demonstrate that UV-C irradiation affected both the AC and total polyphenol contents of 'Maradol' papaya pulp and possibly the mechanisms that involve the synthesis of antioxidant compounds but not exclusively phenolic compounds.

Sensory evaluation

Flavor attributes (sweetness, bitterness, sourness, and astringency), odor (honey, milk, latex, mango, and fermented) and texture (chewiness and fibrousness) of ripe papaya pulp are shown in Figure 2. A significant difference (<0.05) between treatments was found in sweetness (Fig. 2A), with the highest score found in samples treated with UV-C at a dose of 5.76 kJ/m². The above result was difficult to explain, although the RS was high in samples subjected to both UV-C irradiation doses (Tab. 2); only those treated with UV-C at a 5.76 kJ/m² dose were sweeter (Fig. 2), which could be due to the production of higher sugar contents with greater sweetness.

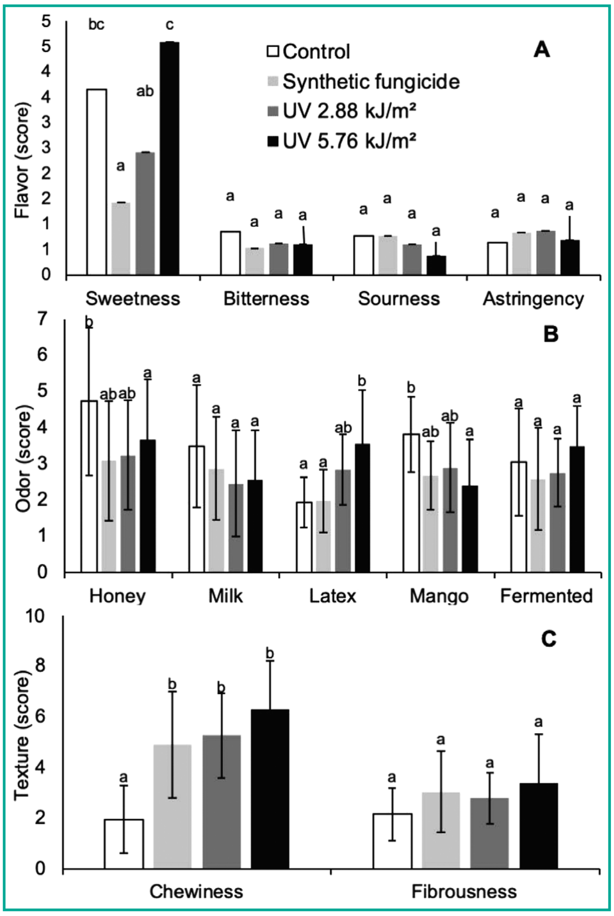

FIGURE 2: *Sensory score of the flavor (A), odor (B), and texture (C) attributes of 'Maradol' papaya pulp treated with a synthetic fungicide or UV-C irradiation prior to storage at 30 °C ± 2 °C for 80 ± 5% RH. The bars show the mean values of eight trained judges. The lines on the bars show the standard deviation. Values with a common letter by the attribute denote statistical equality (Tukey's test, >0.05).*

The trained panel did not detect a significant difference (>0.05) between the treatments for the bitterness, sourness or astringency attributes. Significant differences (<0.05) in odor scores were found for the honey, latex and mango odors (Fig. 2B), with the highest honey and mango odor scores found in the control treatment. These changes can be explained by changes in the physicochemical characteristics during fruit ripening (Tab. 2). The highest latex odor score was found in papaya treated with UV-C at a dose of 5.76 kJ/m² (Fig. 2B). However, no significant differences were detected (>0.05) in milk and fermented odors between treatments.

The irradiation doses that we used in this research partially modified the odors of the 'Maradol' papaya. The untreated fruits, which scored higher than the rest of the treatments in honey and mango odors, can be explained by the higher level of ripeness of these fruits, also denoted by the physicochemical characteristics (Tab. 2) since it has been argued before the UV-C irradiation delays ripening. It has been reported that the most abundant aromatic component in 'Maradol' papaya fruits is methyl butanoate (Pino, 2014), which is also found in mango fruits (Pino and

Queris, 2011). This compound contributes to the typical mango odor in ripe papaya.

For texture, a significant difference (<0.05) was found between treatments for the chewiness score (Fig. 2C), with the lowest value found in the control treatment (1.95 score). The highest chewiness scores were obtained for papaya treated with UV-C light at a dose of 5.76 kJ/m² (6.29 score). This may indicate that the mechanical effort required for chewing the fruit was less than for the untreated fruit, and the panelists generally accepted the fruit treated with UV-C.

However, the fact that the sensory behavior was not related to the firmness (measured instrumentally) may indicate that the treated fruits had modifications in other components related to chewiness, such as lipid and water contents (Simmons et al., 2014). This coincides with other studies that have reported that UV-C energy helps maintain firmness and increase sensory acceptance in papaya (Kulkarni and Karadbhajne, 2015), melon (Manzocco et al., 2011), pineapple and mango (George et al., 2015).

Multivariate data analysis

To reduce the dimensionality of all data, two types of multivariate analyses were conducted. Principal component analysis (PCA) with all the analyzed variables in the ripe fruits is shown in Figure 3. The first two principal components (PC) explain 85.94% of the variation of the original data. It should be noted that when a third component (PC3) was incorporated, 100% of the variability of the data was explained (data not shown). PC1 was influenced on its positive axis by predominantly sensorial traits, while PC2 was positively influenced by physicochemical traits. A positive association of 2.88 kJ/m² UV-C was observed with AC and polyphenol content as well as some sensory descriptors (fibrousness, chewiness, and astringency). These results may indicate that this irradiation dose could stimulate the production of polyphenol compounds and antioxidant capacity (Tab. 2). On the other hand, the treatment with UV-C at 5.76 kJ/m² showed a greater positive association with the variables of reducing sugars and firmness, as well as some sensorial descriptors such as latex and fermented odors, as well as sweetness. The control treatment was negatively associated with some sensory descriptors (bitterness and the honey, mango and milk odors) and color (*b** value). Fruits treated with the synthetic fungicide showed a strong negative association with WL and TA, as well as a weak negative association with color (*L** and *a** values) and acid taste.

A dendrogram based on the Euclidean distance grouped the data into two clusters (C1 and C2) and showed a dissimilarity of 43 (Fig. 3). Based on the analysis of Ward conglomerates, C1 was clearly observed as the UV-C-treated group (2.88 and 5.76 kJ/m²), and C2 contained the group that was treated with the synthetic fungicide and the control group. This grouping validates the effect of UV-C irradiation on the parameters analyzed.

Conclusions

The use of UV-C irradiation at doses of 2.88 and 5.76 kJ/m² positively affected the physicochemical qualities of 'Maradol' papaya fruits. An increase in the polyphenol content was related to an increase in the UV-C dose. The fruits irradiated with 2.88 kJ/m² exhibited up to three times greater antioxidant capacity than that of the other treatments. The sensory evaluation of the flavor, odor and texture attributes of the fruits was not affected by UV-C irradiation but improved the sweetness and chewiness of the fruits.

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Conflict of interest

The authors declare no conflict of interest.

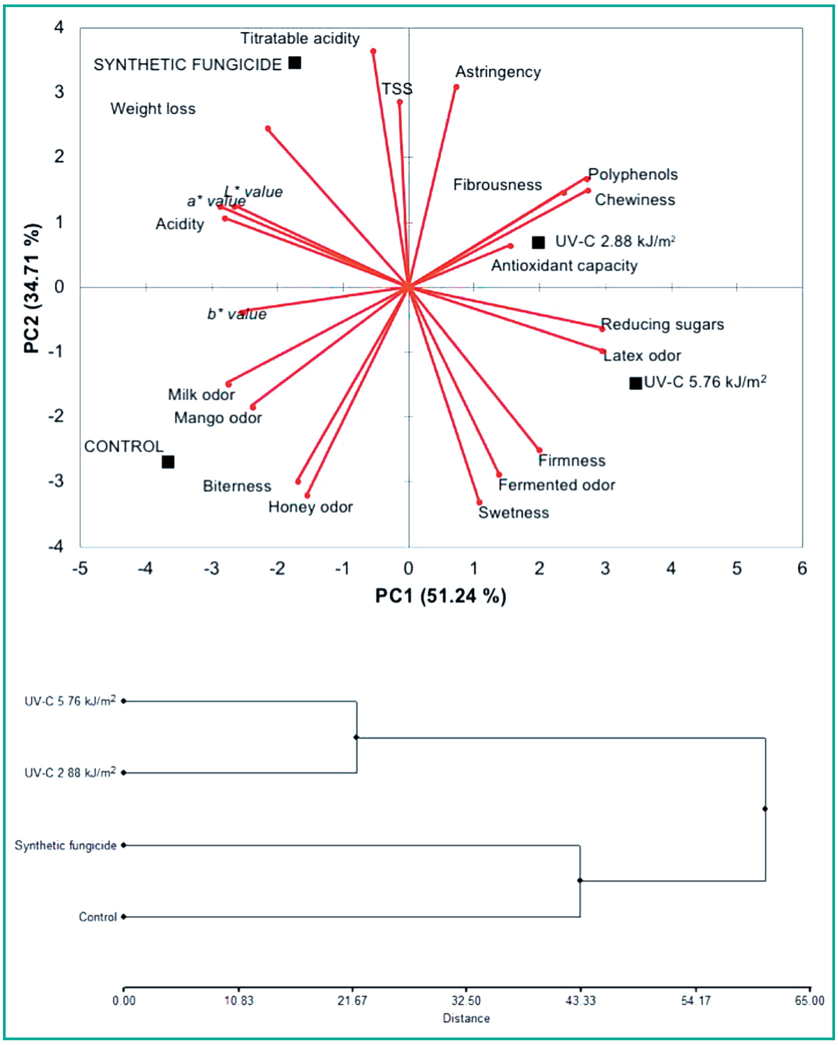

FIGURE 3: *Representations of multivariate analysis of the physicochemical and sensory data of 'Maradol' papaya treated with a synthetic fungicide or UV-C irradiation. Biplot of the principal component analysis (top). Dendrogram based on Euclidean distance with the Ward agglomeration method (bottom).*

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