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ORIGINAL RESEARCH PAPER

IMPACT OF ULTRAVIOLET LIGHT ON QUALITY ATTRIBUTES OF STORED FRESH-CUT MANGO

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Mango (*Mangifera indica* L.) is one of the most important tropical fruits worldwide being considered a good source of antioxidants, carotenoids and ascorbic acid. For this reason, the effects of UV light treatments on bacterial contaminants and quality parameters of fresh-cut mango were investigated. The mangoes were selected, washed, disinfected, cut, inoculated with *Escherichia coli* and *Listeria innocua* at a level of 10^9 and 10^7 CFU/g, respectively and packaged. The artificially contaminated and non-contaminated mango pieces were treated with UV light using different doses of 2.064 and 1.479 kJ/m^2, respectively, at two distances (8 and 15 cm) and further stored at 4˚C for 15 days. The results showed that high doses of UV light and low distance between lamp and sample generate higher levels of bacterial reduction. *L. innocua* showed lower sensitivity to UV treatment than *E. coli*. The physicochemical analyses (colour, texture and pH) were performed every 3 days on the non-contaminated mango samples. The UV treatments had a beneficial effect on stored mangoes texture, while the color deteriorated over time. pH was not affected by the ultraviolet light treatments.

Keywords: quality, bacterial decontamination, fresh-cut mango, ultraviolet light

Introduction

Mango (*Mangifera indica* L.) is one of the world's most important tropical fruits and is considered a very good source of antioxidants, ascorbic acid (by providing around 50% of the recommended daily ingestion of vitamin C) and carotenoid (Charles *et al.*, 2013). Therefore, it represents a fruit of interest for the minimally processed products market.

Fresh-cut processing offers consumers an alternative for the consumption of this fruit, thus providing a highly nutritious, convenient and healthful commodity while maintaining freshness of the non-processed product. However, fresh-cut fruit processing technologies (peeling, slicing and/or cutting) can compromise the

appearance and safety of the product, causing an increase in respiratory rates and a number of biochemical reactions than can result in quality deterioration (Martín-Belloso *et al.*, 2007).

At the same time, fresh-cut fruits, such as mango, have a high risk of microbial deterioration due to the removal of natural barriers because of pollution. In addition, the cut surface can provide an ideal substrate for the growth of microorganisms that cause deterioration or a high risk for public health. The main factors that influence the microbiology of these products are: the source of the product, agronomic practice, technical collection, processing, storage and transportation, postharvest handling and sanitation (Ngarmsak *et al.* 2005).

On the other hand, there are few studies regarding the quality and shelf life after the mango slices processing (Dea *et al*., 2010). The yellow color, fleshy texture and unique flavour are the primary attractions when it comes to this fruit and additionally, the freshness, appearance and safety determine the consumer's satisfaction. Nowadays, several methods of conservation have been studied in order to ensure the safety and maintenance of the original characteristics of the fresh-cut fruits, hence avoiding the unwanted effects (such as browning, tissue softening, changes in taste and contamination by microorganisms) caused by handling and processing and also seeking to meet the current market trends (Caminiti *et al*., 2011; Moody *et al*., 2014; Salinas Roca *et al.*, 2016).

Different technologies are currently used in order to prevent the acceleration of deterioration caused by mechanical operations during processing. Nevertheless, new techniques are required for quality improvement.

Ultraviolet light is a non-thermal conservation method, which is easy to use, economical and lethal for a wide variety of microorganisms. Covering wavelengths between 200 and 400 nm are classified into three types: UV-A (315-400 nm), UV-B (280-315 nm) and UV-C (200-280 nm). UV-C light has the maximum emission peak at 254 nm, and it was found that in this wavelength a much higher germicidal action occurs (Rivera-Pastrana *et al.,* 2007). Additionally, it can induce several defense mechanisms in vegetables tissue metabolically active and cause the production of phytoalexins (substances with antifungal properties) and other defense mechanisms such as changes in the cell wall, defensive enzymes and increased antioxidant activity (González-Aguilar *et al.*, 2004).

The UV light mechanism of action on microbial inactivation refers to the damage caused to microorganisms' DNA because it induces the formation of photoproducts such as pyrimidine dimers that are formed between the molecules of adjacent pyrimidine in the same DNA strand that can disrupt the transcription and translation of DNA (Birmpa *et al.*, 2013). Thereby, by blocking the replication, the death of cells occurs.

For this reason, several authors studied the effect of ultraviolet light upon the quality and microbial inactivation of some whole or fresh-cut fruits such as apple, strawberry, pineapple, star fruit (Beltrán *et al.*, 2010; Manzocco *et al.*, 2011; Márquez and Pretell, 2013; Rojas, 2014) where the results concurred that ultraviolet light treatments are able to retain some quality parameters such as firmness and

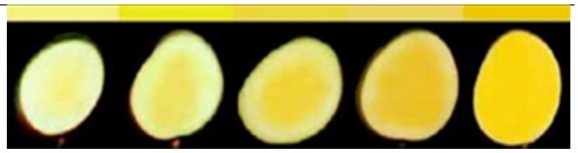
reduce the microbial load. However, little information is available regarding the effectiveness of this treatment on the quality of fresh-cut mango.
The aim of this research was to study the impact of ultraviolet light treatments on the quality attributes of stored fresh-cut mango, color, firmness and pH of fresh-cut mango during 15 days of storage. The survival of the *Escherichia coli* and *Listeria innocua* used to artificially contaminate the mango samples was also followed.

Materials and methods

Sample preparation

Mangoes (*Mangifera indica* L.) from the Tommy Atkins variety were used. The fruits weight ranged between 400 and 450 g. Mangoes were purchased unripe and maintained under controlled conditions at 10°C until they reached the desirable level of type 3 ripeness (Table 1).

Table 1. Sensory indices of maturity in Tommy Atkins mango variety ONASPROMANGO (2014)

Color					
Flesh color					
Maturity					
	Level 1	Level 2	Level 3	Level 4	Level 5
Firmness (lbs-force)	18-20	15-17	10- 13	6-8	3-6
Soluble solids (°Brix)	7-9	8-11	9-11	10-13	12-15

The fruits, as well as the surfaces and tools that came in contact with them (working area, chopping boards and knives), were washed and disinfected with a solution of 200 µL/L of sodium hypochlorite (pH 7.0). Later, the skin was removed with a sharp knife and then cut longitudinally, following the methodology established by Ramos-Villarroel *et al*. (2012). The mango flesh was cut to obtain pieces of 1.5 cm by 2.8 cm wide.

Microbiological analysis

Inoculum Preparation

Escherichia coli CVCM 788 and *Listeria innocua* CVCM 448 strains (Microbiology Laboratory Institute of Science and Food Technology of the UCV, Caracas-Venezuela) were used as a substitute for the *E. coli* 0157:H7 and *L. monocytogenes* pathogenic strains. The original strains were maintained in slants with Trypticase Soy Agar (TSA) (HIMEDIA Laboratories, India) at 5°C. *Listeria innocua* strain was grown on Trypticase Soy Broth (TSB) (HIMEDIA Laboratories, India) supplemented with 0.6 % yeast extract (HIMEDIA Laboratories, India) at 35°C for 15 h (Ramos-Villarroel *et al.*, 2011). The *Escherichia coli* strain was cultivated on a Nutrient broth (HIMEDIA Laboratories, India) at 37°C for 24 h. Serial dilutions from 10^{-1} up to 10^{-9} are made. Sowing was performed at 0.1 mL distributed on culture

plates in duplicate on Nutrient agar (HIMEDIA Laboratories, India). The inoculums size was 10^9 CFU/100g for *Escherichia coli* and 10^7 CFU/100g for *Listeria innocua*.

Inoculation of the samples

An amount of 10 g of mango pieces was inoculated on the surface with 100 µL of culture of *E. coli* (10^9 CFU/mL) and *L. innocua (*10^7 CFU/mL) using a sterile micropipette. At the same time, a set of non-inoculated samples was prepared as control or reference.

Ultraviolet light treatment

The UV treatment was performed with a BGN18 lamp, 115 V- 60 cycle model (Philips, Holland). The emission spectrum was from 200 to 400 nm with a period of 5 min, respecting the distances of 8 and 15 cm. The distances and time were chosen according to results reported by Gomez *et al*. (2013) and Manzocco *et al*. (2011) in their studies. The lamp was placed on the top of the sample holder.

UV dose

To determine the UV radiation intensity (mW/cm^2), a digital radiometer Lutron UV-340 (Taiwan) was used. The applied intensity was measured as the mean of 4 experiments on each side of the lamp and in the middle of it, and it was checked that all the points received the same intensity which allowed the calculation of the application doses of 1.479 and 2.069 kJ/m^2, corresponding to the distances of 15 and 8 cm respectively. The equation used for this calculation (López-Rubira *et al.* 2007) is as follows:

$$D = \frac{I \cdot t}{1000^2} \quad (1)$$

Where: D = applied radiation dose (kJ/m^2), I = radiation intensity area under the UV light emission (W/m^2), and t = exposure time (s)

Packaging conditions and storage

Mango pieces were treated unsealed and then packed in transparent polypropylene 500-cm^3-trays (Performance Plastic Ltd., USA) to be thermo-sealed using an ILPRA Sealbox (ILPRA Systems, CP, Vigevono, Italy). The O_2 and CO_2 permeabilities of the sealing film were 5.2419×10^{-13} mol O_2 m^{-2} s^{-1} Pa^{-1} and 2.3825×10^{-12} mol CO_2 m^{-2} s^{-1} Pa^{-1} at 23 ºC and 0% RH, respectively (ILPRA Systems Films, Italy). The samples were stored for 15 days at 4°C for subsequent analysis every 3 days.

Microbial count

The mango pieces were aseptically removed from each tray and transferred to a sterile blender. Samples were diluted in 90 mL of peptone water (0.1 % peptone + 0.85% sodium chloride, HIMEDIA Laboratories, India) and homogenized for 5 min to make serial dilutions from 10^{-1} up to 10^{-6}. Sowing was performed at 0.1 mL distributed on culture plates in duplicate on Eosin-methylene blue agar (EMB) (HIMEDIA Laboratories, India) to determine *E.coli* and Palcam agar (Merck) by surface-spread method to determine *L. innocua.* The plates were incubated for 24 h at 37°C. The colonies of *E. coli* (black with metallic green center) and *L. innocua* (shiny black with halo) were counted and reported in $\log_{10}$ CFU g^{-1}. The analysis was performed in triplicate periodically every 3 days for 15 days.

Physicochemical analysis

The mango samples used for physicochemical analysis were not inoculated with *E. coli* or *L innocua*.

Color measurement

The color of the samples was determined through the coordinates L* (lightness), a* (green-red chromaticity) and b* (blue-yellow chromaticity). A ColorTec PCM/PSM (USA) colorimeter was used for measurements, and was previously calibrated using a D75 illuminant at an observation angle of 10˚. A standard white tile (Y = 94.00, x = 0.3158, y = 0.3322) was used as reference. Six pieces were evaluated in duplicate for each treatment, according to the methodology described by Ramos-Villarroel *et al.* (2012).

Texture evaluation

The firmness of the mangoes was performed using a Lloyd 500 texture meter (Bognor Regis, UK) with a maximum capacity of 50 N. For the analysis, mango pieces of approximately 1.5 cm thick were penetrated by a probe of 7 mm diameter at a speed of 5 mm/s. The results were expressed in Newtons (kg.m/s), which represents the force exercised by the equipment in order to penetrate the piece of mango for each treatment according to the methodology used by Ramos-Villarroel *et al.* (2012). Two trays were taken at each sampling time and the measurements from six pieces of each tray were carried out.

pH determination

The determination of pH was carried out under the methodology of COVENIN (1317-79). 10 g of sample were weighed, transferred in 90 mL of distilled water, homogenized and the mixture was filtered into a beaker to determine the pH with a pH meter 420 A (Orion Research Inc., EE.UU.). At least six experiments from two replicate packages were conducted.

Statistical analysis

The results of instrumental measurements of physicochemical properties and microbiological counts were analyzed using a two-factor ANOVA (factors: measurement time and ultraviolet light treatments). When significant interaction between factors was observed, the results were analyzed using simple effects; when there was no interaction, the main effects were analyzed. In all cases, the significant differences between means were established using Tukey's test with a confidence level of 95%. The results were expressed as the mean and the corresponding standard deviation of the averages. The InfoStat 2008 (Argentina) version was used for data analysis (Di Rienzo *et al.*, 2008).

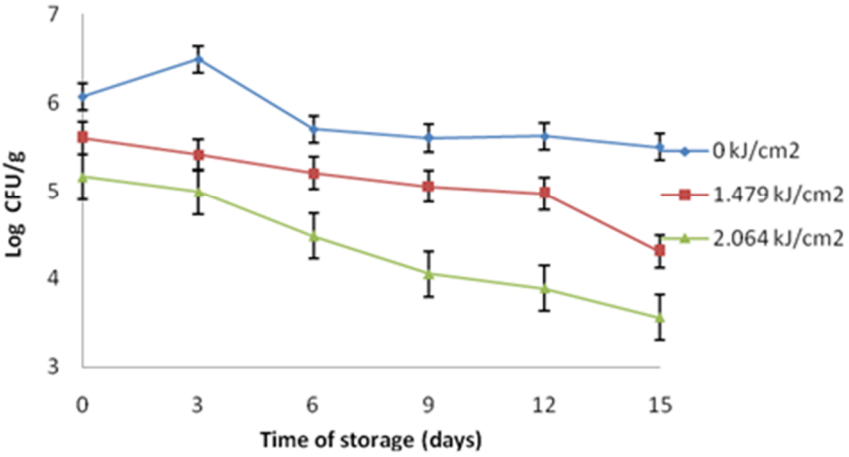
Results and discussion

Microbiological analysis

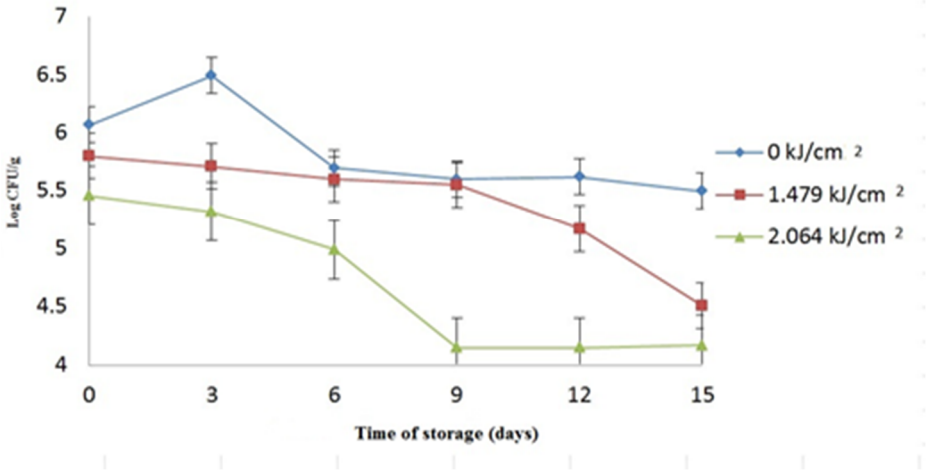
To determine the effectiveness of ultraviolet light on microorganisms such as *Escherichia coli* and *Listeria innocua* inoculated at a level of 10^9 and 10^7 CFU/100g, respectively on fresh-cut mango (*Mangifera indica* L.), the pieces were treated with

ultraviolet light for 5 min at a distance of 15 and 8 cm (doses of 1.479 and 2.064 kJ/m^2 for each treatment).

Figures 1 (a and b) and 2 (a and b) show that the treatments with ultraviolet light and storage time significantly affected ($p<0.05$) the populations of *E. coli* and *L. innocua*. The Tukey test ($\alpha=0.05$), applied for the counts of these microorganisms, determined that the mango pieces subjected to UV light treatments provided lower averages compared to the untreated samples, thus obtaining reductions of 0.61 and 0.64 log CFU/g at 15 cm distance, respectively for each pathogen inoculated in the fresh-cut mango, from the first day of processing at a dose of 2.064 kJ/m^2. For the same dose but at the distance of 8 cm, a reduction of 0.91 and 0.84 log CFU/g, respectively was obtained for each pathogen.

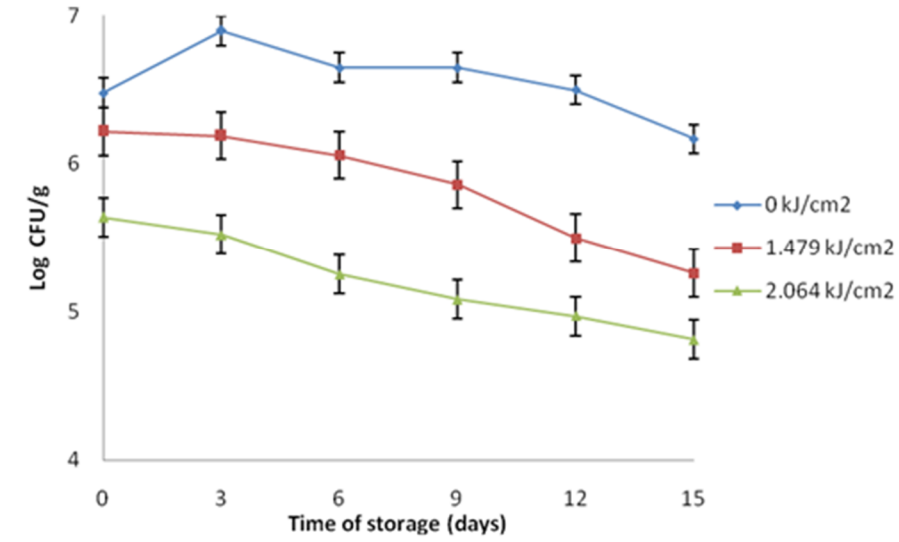


(a)

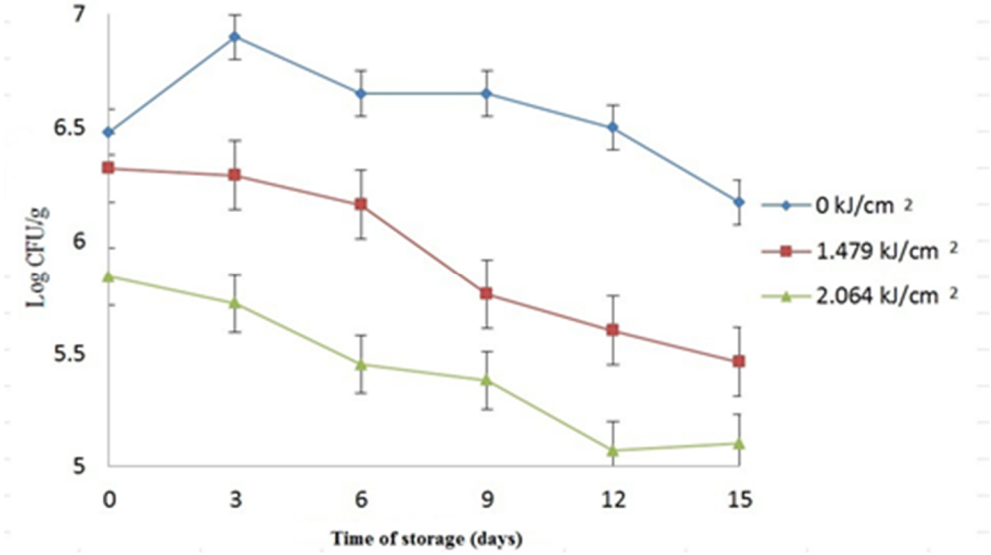


(b)

Figure 1. Influence of distance and dose of the UV light treatment at 8 cm (a) and 15 cm (b) on the evolution of *E. coli* inoculated in fresh-cut mango, during storage at 4°C



(a)



(b)

Figure 2. Influence of distance and dose of the UV light treatment t 8 cm (a) and 15 cm (b) on the evolution of *Listeria innocua* inoculated in fresh-cut mango, during storage at 4°C

Figure 1a shows the log reduction curve of *E. coli* populations treated with doses of 2.064 kJ/m^2 at 8 cm distance during a 15-day storage. The difference was significant for the control ranging from 5.5 to 3.56 log CFU/g. Additionally, it can be observed in Figure 1b that, when the distance was 15 cm, from the first day *E. coli* populations treated with doses of 2.064 kJ/m^2 steadily decreased compared to the untreated, hence obtaining the greatest reduction during day 9 (1.45 log CFU/g), a value that was maintained at the same levels from that day until the end of storage.

Furthermore, it was obvious that the treatment with doses of 1.479 kJ/m^2 reduced *E. coli* populations during the first 3 days of storage. However, during days 6 to 9, the pathogen populations (5.6 and 5.5 log CFU/g at 15 cm distance, for each day, respectively) were similar to those observed in the untreated samples (5.7 and 5.6 log CFU/g at 15 cm distance).

The lower reduction was observed at 15 cm distance and the highest at 8 cm distance for the both doses. In view of the results obtained, it seems evident that the inactivating effect of UV-treatments against of *E. coli* greatly depends on the dose and distance between from the lamp and the sample.

The evolution of *L. innocua* population in controls and UV light treated samples has been investigated immediately after light exposure and during the 15-day storage period at 4°C. The obtained results are presented in Figure 2a and b for different doses and distances between the lamp and the sample. In the case of distance at 8 cm (Figure 2a), the low level of reduction on day 15 (1.36 log CFU/g) was observed for UV treatment at 2.064 kJ/m^2, while the slightly microbial reduction (0.91 log CFU/g) was found at a dose of 1.479 kJ/m^2.

However, regarding the results of *L. innocua* population, it can be observed in Figure 2b that for the samples treated with doses of 2.064 kJ/m^2 at 15 cm distance, the reductions were 1.2 log CFU/g for the 3rd day of storage compared to the untreated mango samples. On the other hand, for the samples subjected to UV light treatment at a dose of 1.479 kJ/m^2 and the same distance, lower levels of reduction were achieved compared to the previous treatment (0.61 log CFU/g for the 3rd day). However, the population of *L. innocua* for all treatments tended to decline steadily until the final day of storage.

At the same time, it is very important to note that higher doses of UV-light and lower distance between the lamp and the sample resulted in an increase of bacterial reduction, indicating that the energy and distance applied were determining factors in the decontamination process of the treated samples.

This could be explained through the mechanism of UV light action. Because many cellular components of the bacteria absorb the ultraviolet light, the nucleic acids are the most affected component (Montoya, 2008). At higher levels of applied energy, higher damage is implied in the bacterial cell.

In the literature, there are no studies regarding the effect of ultraviolet light on *E. coli* and *L. innocua* used for artificial contamination of the fresh-cut mango. However, the levels of reduction of bacterial burden obtained in this study were similar to those reported by Birmpa *et al.* (2013) who studied the effect of UV light on strawberries inoculated with a cocktail of four bacteria, including *E. coli* and *L. innocua*. The strawberries were subjected to UV light at several exposure times such as 10, 20, 30, 45 and 60 minutes at the distance of 8 cm. The researchers obtained reductions of 1 and 1.4 log CFU/g, for the populations of *L. innocua* and *E. coli* respectively; when the exposure time to UV light was prolonged from 30 to 60 minutes, the authors reported doses between 3.6 and 7.2 J/cm^2. In the same way, Gómez *et al*. (2013) studied the effect of ultraviolet light on fresh cut apples exposed for 10 min. (5.6 kJ/m^2), 20 min. (8.4 kJ/m^2) and 25 min. (14.1 kJ/m^2), with a distance

of 10 cm, with and without anti-browning pre-treatments, inoculated with microorganisms such as *L. innocua*, *Saccharomyces cerevisiae* and *E. coli*. They assessed that the treatment with UV-C proved to be more effective in the apple pieces exposed to this technology without pre-treatment, thus obtaining log reductions between 1.0 and 1.9 log CFU/g for all the studied species, certifying that *L.innocua* is more resistant to inactivation than *E. coli*. Different authors reported that the levels of inactivation obtained by UV light treatment, process used for disinfection, depend on the kind of substrate, the initial inoculum and the type of bacteria (Otto *et al.* 2011, Birmpa *et al.* 2013).

In this regard, *L. innocua* was more resistant to UV light than *E. coli*. This resistance can be attributed as a result of the difference in the cell wall structure of the Gram positive bacteria, which is composed of a homogeneous thick layer of 10 to 80 nm of peptidoglycan as major component, with associated polysaccharides and a special class of polymers such as teichoic acids (Stanier*et al*. 1992). Thus, a greater resistance was generated in regards to the UV light penetration, inactivating microorganisms mainly due to the induction of the pyrimidine dimers formation that alters the DNA helices and blocks the microbial cells replication, destroying the ability of reproduction and other cell functions (Márquezand Pretell, 2013). On the contrary, the Gram negative bacteria have a fine internal peptidoglycan layer and an outer membrane that the UV light can penetrate more easily (Stanier *et al.* 1992). In general, it is considered that the resistance to UV-C radiation is in this order: Gram negative < Gram-positives < yeasts < bacterial spores <fungus <virus (Adams and Moss, 1995).

In the case of *L. innocua* (Gram-positive bacteria), its extensive distribution in nature offers a greater adaptability to various substrates. This property may serve as a reservoir from the animals stool, vegetation, sewage (wastewater from factories), silage and the food production environment, that are within the range of pH, temperature and water activity where this organism can develop (Michanie 2008). The Gram-negative bacteria such as *E. coli* are found primarily in the darkness of the lower intestine of warm-blooded animals, including humans, sewage or soil contaminated with animal feces (Kayzer *et al*. 2005). In view of this sensitivity to solar radiation, the sensitivity is higher and therefore the bacteria are less resistant to UV light as a result of the characteristics of their primary habitat.

On the other hand, in this study the tendency of *E. coli* and *L. innocua* population on the untreated fresh-cut mango was different from the samples treated with UV light during the first days of storage at 4°C. The counts for the populations (6.49 log CFU/g of *E. coli* and 6.9 log CFU/g of *L. innocua*) increased during the first 3 days of storage. However, the counts at the end of the storage period (5.96 and 6.17 log CFU/g respectively) did not exceed the values of the initial counts (6.07 and 6.48 log CFU/g for *E. coli* and *L. innocua*, respectively) in the untreated samples. These results are comparable to those obtained by Castro del Campo *et al*. (2004) who showed that the cooling temperature is not a limitation in the development and survival of *E. coli*. Instead, Michanie (2008) reported that *Listeria* spp. can grow at temperatures from less than 0.4 and 45°C and that is also able to withstand a wide

pH range, from 4.39 to 9.0. This fact may explain why this pathogen reproduces in the untreated fresh-cut mango during the first 3 days of storage under refrigeration.

However, after the third day of storage, the populations of *L. innocua* declined, this could be the result of the pH sample (<3.68) because the minimum pH value reported for the growth of *Listeria* genus is 4.39. Similar results were found by Gómez *et al.* (2013) who studied the effect of UV-C light on fresh cut apples that were inoculated with *E. coli* and *L. innocua.* These authors showed that the low pH (3.3 to 3.4) of the *L. innocua* samples was not reproduced in the control samples, although a slight increase of the population was observed after 7 days of storage (0.24 log CFU/g).

In general, the pH is a controlling factor for different sources of food that allows or limits the chemical and biochemical reactions involved in the microorganisms cellular metabolism. The pH affects the permeability of the membrane that corresponds to each type of microorganism, so that when the pH of the medium is more acidic or more alkaline than the tolerable levels of the bacterial cell, the balance between the internal and the external pH tends to be maintained, although, when the membrane is saturated, the transfer of cations or anions indispensable for life of the cell is limited. At the same time, the activities of the enzymatic systems involved in the cellular metabolism are usually related to an optimal pH level and any change may cause a decrease of the enzymatic activity and the inhibition or reduction of microbial growth (Bello, 2000). This explains why after 3 day of storage the *L. innocua* populations declined in the untreated mango samples during this storage time. Similarly, we can consider that the *E. coli* reductions could be caused by competition with native microflora and their metabolic activity, which could influence their survival and reproduction (Ramos-Villarroel *et al*., 2012) mainly because this pathogen has the ability to survive in acidic conditions (pH from 2.5) and to grow at temperatures between 5 and 7˚C (Sánchez *et al.*, 2009).

Additionally, it can be observed in Figures 1(a and b) and 2 (a and b) that the survivors of *E. coli* and *L. innocua* in treated samples had a tendency to decrease throughout the storage period as a result of UV light treatment lesions and physicochemical changes in the samples and package (gases composition which was not evaluated in this study). However, studies indicate that there are changes in gases composition during storage (Ramos-Villarroel *et al*., 2012).

According to the obtained results, it can be considered that UV light as non-thermal preservation method is an efficient technology for the bacterial decontamination in fresh-cut mango at a dose of 2.064 kJ/m^2, exposure time of 5 minutes and at the distance of 8 cm.

Physicochemical analysis

Color measurement

L* (lightness), a* (green-red), and b* (blue-yellow) parameters were measured in the treated and untreated mango samples (Table 2).

Significant differences ($p < 0.05$) were found between the color parameters (L*, a* and b*) of the untreated fresh mango, or mango treated with UV light throughout storage.

Table 2. Changes in the parameters L*, a*, b* in the case of ultraviolet light treated and untreated fresh-cut mangoes during storage at 4˚C

Storage (days)	Treatments (kJ/cm^2)	L*	a*	b*
0	0	66.79 ± 2.4909 $^{C-F}$	-0.15 ± 0.1440 ^{AB}	62.01 ± 8.3128 $^{D-F}$
	1.479	68.04 ± 1.9053 $^{D-G}$	-0.12 ± 0.1931 ^{A}	63.51 ± 3.7180 ^{F}
	2.064	65.61 ± 2.9101 $^{C-E}$	-0.10 ± 0.1010 ^{AB}	64.65 ± 2.9765 ^{F}
3	0	65.52 ± 2.3177 $^{C-E}$	0.08 ± 0.1948 $^{A-C}$	63.10 ± 4.2683 ^{EF}
	1.479	63.55 ± 4.5664 $^{B-D}$	-0.04 ± 0.9439 $^{A-E}$	61.56 ± 2.8191 $^{D-F}$
	2.064	65.11 ± 2.4730 $^{C-E}$	0.05 ± 0.2867 $^{A-D}$	62.86 ± 2.6405 ^{EF}
6	0	75.40 ± 4.6240 ^{H}	0.34 ± 0.1228 $^{C-E}$	59.67 ± 2.3518 $^{C-F}$
	1.479	72.39 ± 6.8584 $^{F-H}$	0.06 ± 0.2459 $^{A-C}$	53.73 ± 9.7031 $^{B-D}$
	2.064	73.45 ± 2.8683 ^{GH}	-0.04 ± 0.1381 $^{A-E}$	54.48 ± 3.9704 $^{B-E}$
9	0	70.08 ± 3.4327 $^{E-H}$	0.41 ± 0.1881 ^{DE}	66.16 ± 4.7667 ^{F}
	1.479	74.55 ± 3.5830 ^{H}	0.51 ± 0.2735 ^{A}	58.57 ± 6.1076 $^{C-F}$
	2.064	70.93 ± 2.8295 $^{E-H}$	0.10 ± 0.1715 $^{A-D}$	63.51 ± 3.5271 ^{F}
12	0	57.39 ± 7.0598 ^{B}	0.36 ± 0.1369 $^{C-E}$	51.32 ± 4.5978 ^{BC}
	1.479	61.43 ± 5.5236 ^{BC}	0.19 ± 0.2438 $^{A-E}$	60.93 ± 5.5230 $^{D-F}$
	2.064	58.59 ± 5.3755 ^{B}	0.17 ± 0.1438 $^{B-E}$	58.76 ± 6.3331 $^{C-F}$
15	0	45.53 ± 6.8349 ^{A}	0.45 ± 0.2241 $^{A-E}$	43.40 ± 13.2028 ^{B}
	1.479	48.73 ± 6.0598 ^{A}	0.24 ± 0.2637 ^{E}	35.10 ± 9.1108 ^{A}
	2.064	47.97 ± 3.4021 ^{BC}	0.10 ± 0.0695 $^{A-E}$	33.04 ± 4.2423 ^{A}

Average ± standard deviation (n=20); different letters in the same column stand for significant differences ($p < 0.05$).

The lightness (L*) was significantly different ($p<0.05$) with regard to the UV light treatments and the effect of storage time. Tukey test showed that the L* values are similar for the samples treated with UV light and the untreated samples. However, the L* values in mango pieces treated at doses of 1.479 kJ/m^2 (15 cm) are slightly higher than for the untreated samples and for those subjected to doses of 2.064 kJ/m^2 (8 cm). L* values increased during days 6 and 9 but decreased during the remaining days of storage, compared to the initial day of all treatments. From the 9th day, the treated and untreated samples underwent the browning process, being less noticeable in the samples exposed to doses of 1.479 kJ/m^2. Therefore, lower doses of UV light allowed for a smaller extent of the browning process of the fruit until the final point of storage. This might indicate that the UV light, and especially the UV-C, may produce an important decrease in the carotenoid content. UV-C may affect the concentration of some other compounds and can catalyze the oxidative changes, leading to discoloration (Jay, 1997).

These results are comparable to those found by Márquez and Pretell, (2013) who indicated that the reduction of the L* value is related to the decrease of brightness that was used as an indicator of the browning in fruits. It is also mentioned that the L* values from the fresh-cut mango, Keitt variety, treated with UV-C (doses of 0.7 y 14 kJ/m^2) irradiation decreased over the 15 days of storage, thus acquiring better results for those samples treated with a dose of 7 kJ/m^2.

Additionally, Souza (2014) studied the minimally processed mangoes, Tommy Atkins variety, and the effect of UV-C irradiation doses of 0 0.56, 1.13, 1.70 and

2.26 kJ/m^2 on the rate of product browning that was stored under refrigeration for 12 days. This author observed no browning in mango samples treated with doses of 1.13 and 1.70 kJ/m^2, compared to those fruits exposed to doses of 2.26 kJ/m^2 which show a higher rate of browning. Other authors also reported low L* values for the same substrate only when the samples were subjected to intense light pulses (ILP) treatment which comprises the wavelengths from the UV light to near infrared spectrum. These authors indicated that the luminosity (L*) decreased over storage time although in a less obvious way for the samples treated with ILP (Charles *et al.*, 2013).

The effects of UV light on color for a* parameter are presented in table 2. Significant differences were observed ($p<0.05$) regarding the effect of radiation and storage time. Tukey test ($\alpha=0.05$) showed that the trend of a* values increased from negative to positive, hence indicating an increase in the chromaticity from - 0.12 to 0.36 for the untreated mango pieces (control). There is a variation in color from reddish to green tones related to browning, whereas for the treated samples at the distance of 8 cm (2.064 kJ/m^2), the values oscillated from -0.10 to 0.28 during the refrigerated storage. According to the obtained values, the samples treated at 8 cm showed a lower brown coloration when compared to the untreated pieces of mangoes, due to the presence of a lower value of the green color. These processes are related to the tissues senescence and, consequently, to the release of enzymes and substrates involved in the browning reactions (Gómez-López *et al.*, 2005)

These results are similar to those obtained by Charles *et al.* (2013) who studied the effect of intense light pulses on fresh-cut mango. These authors evaluated the a*, b* and L* parameters and obtained the increase of a* value over 15 days of storage, having a higher value in the untreated samples compared to ILP treated samples, which maintained their values close to zero.

Regarding the previous study, the authors considered that the increased values of a* parameter coincide with the decrease of the brightness values (L*) of the sample. Because the browning process is related to the increase of a* parameter that affects brightness, since the L* values are close to zero and are also related to the lack of clarity, which represents the presence of browning pigments.

Additionally, Marquez and Pretell (2013) also obtained similar results in terms of chromaticity parameter (a*), whose values increased over the storage time. Subsequently on the 15th day, the samples treated with an irradiation dose of 7 kJ/m^2 presented a better color compared to the control sample. On the other hand, Table 2 showed that the untreated mango pieces had higher a* values than the UV light irradiated samples. This result showed that the untreated samples underwent a more rapid browning due to the obtained values that indicated a chromaticity increase to several green shades.

Regarding the b* color parameter, significant differences were observed regarding the effect of storage time and the effect of UV irradiation treatments (Table 2). The values of b* decreased over the storage time despite suffering an increase between 6 and 9 for the untreated samples.

Nonetheless, it must be noteworthy that the b* values decreased from 63.51 to 34.42 for the samples that were treated at doses of 1.479 kJ/m^2, a result that was also similar for the mango pieces that were treated at 2.064 kJ/m^2 and that presented values from 63.01 to 34.00. The behaviour of both treatments was similar to each other throughout the storage period. This indicates that during storage the b* parameter is affected in regard to the fresh-cut fruit, which relates in turn to the loss of yellow hues of the mango pieces.

These results are comparable to those obtained by Charles *et al.* (2013) who reported that the b* values decreased in the same manner as the L* parameter, but in a less obvious way for the samples treated with ILP.

On the other hand, Marquéz and Pretell (2013) observed that the b* parameter decreased with the storage time, which was in line with the loss trend of the initial yellowish tones seen on the fruit pulp.

Therefore, based on the results obtained in this study, it was found that the treatment at low doses of UV (1.479 kJ/m^2) can promote the conservation of fresh-cut mango color, although higher doses can damage this feature at the same level as the untreated samples. When the fruits are treated with high doses of UV light, a stress is generated in the cellular tissue, thereby causing irreversible damage to the membrane and probably a stronger action of polyphenol oxidase which is an enzyme that accelerates the enzymatic browning thus generating the production of brown pigments (Souza, 2014).

Therefore, it would be possible to optimize the UV light treatments by using antioxidants to better maintain the color characteristics of fresh-cut mango.

Texture evaluation

Significant differences ($p < 0.05$) were found between the untreated or the UV light treated fresh-cut mango and storage time (Figure 3). Tukey test showed that mango pieces treated with UV light at doses of 2.064 kJ/m^2 and 1.479 kJ/m^2 exhibited higher values of firmness (19.18 and 16.01 N, respectively) when compared to the untreated samples (13.56 N), thus showing a better retention of this parameter.
Charles *et al.* (2013) evaluated the effect of the intense light pulses upon the firmness of fresh-cut mango, Kentt variety, where the most important component of the emitted spectrum light was the UV light, hence showing that the untreated mango pieces suffered a high loss of firmness after 2 days of storage at 6°C. Whereas the samples treated at 8 J/cm^2 showed no diminution of the firmness values, maintaining this parameter during 8 days of storage.

Figure 3 shows that the untreated mango pieces suffered a continuous decline of firmness during the 15 days of storage. The firmness loss was about 15.26 N between day 3 and 6. On the other hand, the samples treated at doses of 2.064 kJ/m^2 and 1.479 kJ/m^2, had a decrease between 3.50 and 5.60 N, respectively, in the same period. Therefore, in this study, the application of the highest dose of UV light resulted in a smaller degree of firmness loss. Enzymes and substrates are normally located in different cellular compartments and are actively adjusted. However, the destruction of the surface cells and the injury stress of underlying tissues occur during the

processing of the fruit, with the release of some metabolites such as pectic enzymes, that are accounted for the firmness changes (Knee, 1973).

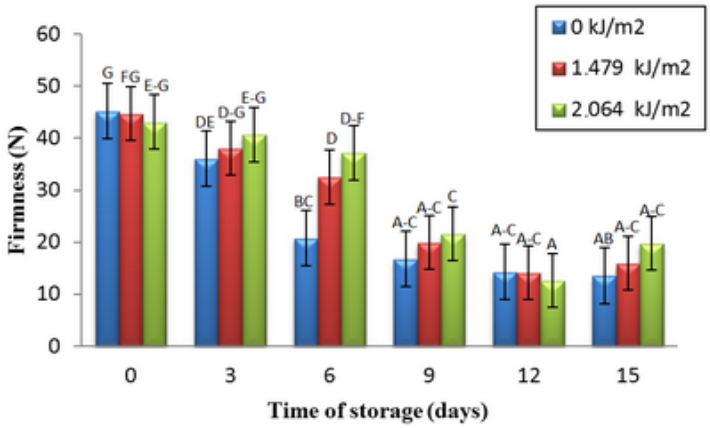


Figure 3. Changes in the firmness of the UV light treated and untreated fresh-cut mangos during storage at 4°C

It is very important to note that fruits have living tissues that once cut their metabolic respiration process continues, hence changing the gas composition of the medium by releasing CO_2, energy and heat, with or without oxygen consumption. This fact implies that the enzymatic oxidation of organic molecules such as carbohydrates (sugar and starch), organic acids and proteins are responsible for the softening of the tissues and other changes (Rangel-Marrón and López-Malo, 2012). Thus it can be explained why the firmness of the mango pieces decreased over time and as well that a higher levels of firmness was achieved for the untreated UV light samples. In turn, this process is affected by many factors such as: cutting size, handling during processing, fruit variety, maturity and type of tissue (Rangel-Marrón and López-Malo, 2012).

At the same time, during the evaluations of firmness, further dehydration was obvious on the surface of fresh-cut mango treated with UV light compared to the untreated samples.

Souza (2014) showed the effect of the UV light and intense light pulses treatments on the quality of Tommy Atkins variety mangos. This author observed the formation of a thin dried coat, thus observing the same phenomenon when the surfaces of the mangoes were subjected to UV light. At the same time, Manzocco *et al.* (2011) also reported that the minimally processed apple samples treated with UV light were dehydrated and lost the turgor at the beginning of storage, hence generating greater firmness in the tissue.

Furthermore, in this study the loss of firmness at the end of the storage period did not exceed the values of the untreated samples. The values for the fresh-cut mango treated with UV light from a distance of 8 and 15 cm were estimated between 19.80 and 16.01 N for the samples treated at 2.064 and 1.479 kJ/m^2, respectively.

In this sense, Marquéz and Pretell (2013) studied the effect of radiation on mango slices, Kent variety, that were treated with a combined solution of calcium chloride (1% p/v), ascorbic acid (1% p/v) and ultraviolet light treatment (0, 7 and 14 kJ/m^2) and stored at 5°C. The treated samples retained their firmness for 15 days of storage, hence showing much greater firmness retention for mango slices treated with doses of 7 kJ/m^2. Similarly, in another study, it was evaluated the effect of UV-C light treatments combined to exposure time (during 10 and 20 min) upon the firmness of mangoes, Keitt variety, where it was observed that the UV-C treatment reduced significantly the deterioration and firmness maintenance of fruits during storage. Finally, the fruits treated with UV-C for 10 min maintained a better firmness than control fruits (González-Aguilar *et al.*, 2005).

Therefore, it is considered that the UV light as non-thermal technology allows the maintenance of firmness of the fresh-cut mangoes during refrigerated storage, mainly because the firmness preservation of fruits has been associated with higher levels of polyamines, which are produced as a result of UV light treatment. These polyamines function mechanism is similar to that of calcium; thereby it involves the formation of cation cross-links with pectic acid by limiting the accessibility of the cell wall to degradative enzymes (Charles *et al.*, 2013). High doses of UV light also cause the breakdown of cell membranes, thus increasing the enzyme-substrate contact and decreasing the intracellular volume, causing the loss of the turgor in fruits tissue cells (Manzocco *et al*., 2011).

Moreover, there are other factors that influence the tissue softening of the fresh-cut mango as the injuries suffered due to the minimal processing of fruits, which allows for the dispersion of some pectic enzymes, thereby causing the changes in firmness (Knee, 1973; Ramos-Villarroel, 2012). Furthermore, it was observed the acceleration of ethylene production by fruits, which also contributes to the softening of the minimally processed products (Pech *et al*., 2003; Ramos-Villarroel *et al*., 2012).

When doses of 2.064 kJ/m^2 were used and treatments were performed at a distance of 8 cm between the UV lamp and the sample during 5 minutes of exposure, UV light technology maintained the firmness of fresh-cut mango during 6 days of storage at 4°C. In general, and according to the results obtained, the treatment with UV light can be considered a good technology for maintaining the firmness of stored fresh-cut mangoes.

pH determination

Statistical analysis shows significant differences ($p<0.05$) regarding the effect of storage time 4˚°C upon the pH values of the investigated mango samples. Tukey test ($\alpha=0.05$) showed that the pH in the samples increased between day 0 and 3 days.

These results are similar to those presented by Souza (2014), because no significant differences were reported regarding the effect of treatment with UV-C light on pH and acidity of fresh-cut mangoes, Tommy Atkins variety. In their study, the fruits showed higher values of total acidity. Furthermore, other authors found no significant differences between the effect of treatments on the pH of other substrates

such as whole grenades and minimally processed star fruit (López-Rubira *et al*., 2007; Andrade-Cuvi *et al*., 2010).

Is must be noteworthy that the acidity reduction and the pH increase of fresh-cut fruits are indicators that the product is entering the stage of senescence as well as the foregoing can be observed during the period of storage because the organic acids were used as substrate in the respiratory activity (Souza, 2014).

In general, the pH is one factor that allows for the control of enzymatic reactions and the microbial growth when it comes to fruits. This is mainly due to the fact that the optimum pH needed for the growth of almost all bacteria, which is associated with food, is in the range 6.5-7.5. However, some pathogenic bacteria can grow at pH 3.0 and other deteriorative bacteria can grow in very acidic conditions like pH 2.0 (Alzamora *et al.*, 2004).

In this sense, it can be considered that the UV light treatments do not affect the pH of cut-fresh mangoes; however, the storage time caused an increase of the samples pH as a result of the decrease of organic acids consumption that contributed to the senescence effect of UV light.

Conclusions

Treatments with UV light applied on fresh-cut mangoes reduced *Listeria innocua* and *Escherichia coli* growth during storage, most probably as the result of lesions caused in the bacteria. Additionally, the dose of 2.064 $kJ/m^2$and the distance of 8 cm were more effective to reduce the populations of both pathogens. At higher doses of UV light and lower distance between the lamp and the sample, were higher levels of bacterial reduction. *L. innocua* strain was more resistant to UV light treatment than *E. coli* in the fresh-cut mango. The treatment with doses of 2.064 kJ/m^2 was enough to maintain the firmness of fresh-cut mango during 6 days of storage. UV light affects the color of the samples. However, mango pieces treated with doses of 1.479 kJ/m^2 maintained their color better than the untreated samples and those which were treated with higher doses. The pH was not affected by the UV light treatment, no more that it was affected by the storage time. In general, UV light, as a non-thermal conservation technology, promotes the maintenance of the quality characteristics and is effective for bacterial decontamination of fresh-cut mango. However, our study suggests the use of quality stabilizing compounds before the UV light treatments in order to better improve physicochemical characteristics of fresh-cut products and thus extend the shelf life of fresh-cut mango.

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