

# Ultraviolet-C Light Effect on Pitaya (*Stenocereus griseus*) Juice

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## Abstract

Pitaya (*Stenocereus griseus*) juice, obtained from fresh pitayas, was processed using a continuous ultraviolet-C (UV-C) light ( $57 \mu\text{W}/\text{cm}^2$ ) system. Juice was processed at five flow rates (0.46, 3.28, 6.57, 16.49 and 30.33 mL/s) and five treatment times (5, 10, 15, 20, and 25 min). Fresh juice was used as control. Some physicochemical (pH, total soluble solids, color, and betalains), antioxidant (total phenolic compounds and antioxidant activity), and microbiological (aerobic mesophylls bacteria and yeasts plus molds) characteristics were assessed in fresh and UV-C processed juices. It was observed that the UV-C treatments did not affect pH and total soluble solids in juice. The total change in color ( $\Delta E$ ) increased as treatment times increased; however,  $\Delta E$  values were reduced at high flow rates. The betalains and total phenolic compounds contents were reduced as flow rates and treatment times increased; consequently, the antioxidant activity lessened in juice. A maximum reduction of 2.11 and 1.14 log cycles was observed for mesophylls and yeasts plus molds, respectively, in the UV-C light treated pitaya juice.

**Keywords:** Antioxidant activity, Betalains, Phenolic compounds, Pitaya juice, UV-C light

## 1. Introduction

Emerging technologies such as high hydrostatic pressure, pulsed electric fields, ultrasound, and ultraviolet light have been used to obtain food products with characteristics similar to fresh products that consumers are demanding today. The short-wave ultraviolet-C light is a physical method that does not generate chemical residues in the food and today is used for water and surfaces disinfection (Quek & Hu, 2008). The UV-C light (254nm) is easy to use for disinfection purposes of liquid foods. It has lethal effects on micro organisms such as bacteria, viruses, protozoa, yeasts, and molds (Begum, Hocking-Ailsa & Miskelly, 2009). The germicidal effect of UV-C light on micro organisms is at the DNA level. The absorption of UV-C light generates electronic changes that may cause breaking of the DNA bonds; therefore, microbial cells could be compromised. The photoproducts (pyrimidine nucleotide bases), generated by the application of UV-C light, block the DNA transcription and replication; even more, inhibits cell functions that may cause the cell death (Guerrero-Beltrán & Barbosa-Cánovas, 2004).

Fruit juices are usually pasteurized in order to inactivate micro organisms and enzymes responsible for undesirable changes. However, the sensory characteristics of the pasteurized food product could be damaged by the high temperatures used for processing (Ibarz & Barbosa-Cánovas, 2002). In 2000, the Food and Drug Administration (FDA) approved the use of UV-C light as a method for “cold pasteurization”; however, it was

also advised that the reduction of resistant pathogens should be at least of 5 log cycles (FDA, 2001) to ensure the effectiveness of the process.

The UV-C light has recently been used for researching in the fruit juices processing area, but this has been mainly focused on the inactivation of microorganisms (Guerrero-Beltrán & Barbosa-Cánovas, 2005; Gabriel & Nakano, 2009; Lu *et al.*, 2010), enzymes (Barka *et al.*, 2000; Guerrero-Beltrán & Barbosa-Cánovas, 2006), and changes in color (Keyser *et al.*, 2008). Few researchers have comprehensively assessed the UV-C light effects (Pala & Tocluku, 2010; Falguera *et al.*, 2011) on other fruit juice components. The UV-C light treatment of liquid fruit products has to be performed carefully since some requirements should be accomplished. Among these requirements is to sustain turbulent flow to warranty that the whole liquid is reached by the UV-C light to deliver a microbiologically safe food product (FDA, 2000). Despite of this and due to the presence of colored compounds, organic compounds, and suspended matter, characteristic that may affect the UV-C light penetration into the liquid food product, the light transmission might be attenuated. As a result the UV-C light efficiency could be reduced (Caminiti *et al.*, 2010).

Pitaya (*Stenocereus griseus*) is a red-peel fruit produced by a species of the *cactaceae* family. The fruit is surrounded of large prickles similar to small needles. It has an oval or spherical shape. Pulp fruit possesses weened delicate flavor; it is also juicy and has small black seeds that crunches “pleasantly” when masticate them (Ayala *et al.*, 2007). The fresh fruits weight ranges from 85.9 to 398.5g. Pulp and peel make 76-84 and 16-24%, respectively (Luna, 2006). The total soluble solids content, pH, and titratable acidity (as citric acid) range 10-11, 3.9-5.0, and 14.0-0.5 %, respectively (Luna, 2006). One of the main problems of fresh pitaya is the short shelf-life (3 to 5 days); therefore, it is important to use the appropriate technologies to increase its shelf-life in a fresh fashion or to obtain pitaya processed products such as juices and nectars.

The aim of this study was to evaluate the physicochemical, microbiological, and antioxidant characteristics of pitaya juice treated with ultraviolet-C light.

## 2. Materials and Methods

### 2.1 Pitaya juice

“Pitaya of May” (*Stenocereus griseus*) was obtained from the municipalities of Cuauhtémoc Huitziltepec and Tepeyahualco, Puebla, Mexico. Fruits were sorted and chosen free from physical and microbiological damages. Fruits were disinfected with a solution of sodium hypochlorite (150 ppm). Pitayas were peeled and homogenized using a Black and Dekker domestic food processor (Towson, Maryland, USA). Afterward, juice was sieved (0.297 mm) to remove seeds and some large particles suspended in pulp.

### 2.2 UV-C light equipment

Pitaya juice was processed using an ultraviolet light system, similar to a double-walled heat exchanger, assembled at the University of the Americas Puebla. The UV-C lamps, acquired from Light Sources, Inc. (Orange, Connecticut, USA) were 303 and 15 mm in length and diameter, respectively. Lamps were of 17 W in intensity to deliver a dose of  $57\mu\text{W}/\text{cm}^2$ . The UV-C flowing system hosts a volume of 430 mL into the double-walled system. The system has an inner quartz tube with an outer diameter of 2.2 cm and a stainless steel external tube with an inner diameter of 4.8 cm.

### 2.3 UV-C light treatment

Pitaya juice (600 mL) was placed in a double-walled vessel which was kept at 4° C using a Cole Parmer Cooling Polistat Circulator system (Vernon, Illinois, USA). The juice was pumped and recirculated in the UV-C system using a 75553-71 Master Flex peristaltic pump (Vernon, Illinois, USA) at 5 different flow rates (0.46, 3.28, 6.57, 16.49, and 30.33 mL/s). The processing time of juice, for each flow rate, was 5, 10, 15, 20, and 25 minutes corresponding to doses of 0.171, 0.342, 0.513, 0.684, and 0.86  $\text{kJ}/\text{m}^2$ , respectively (Guerrero-Beltrán & Barbosa-Cánovas, 2006). Untreated juice was used as control. The UV-C light treatment was performed in duplicate.

### 2.4 Physicochemical characteristics

Total soluble solids and pH were evaluated according to the 932.12 and 981.12 AOAC (2000) methods, respectively.

### 2.5 Color

Ten milliliters of pitaya juice were placed in a small petri dish (6 cm in diameter and 1.5 cm in height) to measure the *L* (luminosity, white-black), *a* (green-red), and *b* (yellow-blue) color parameters, in the Hunter scale,

using a Gardner Colorgard® System 05 (Geretsried, Germany) colorimeter in the transmittance mode. The total change in color ( $\Delta E$ ) was calculated using the next equation:

$$\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2}$$

Where  $L_0$ ,  $a_0$ , and  $b_0$  and  $L$ ,  $a$ , and  $b$  are the color parameters before and after the UV-C light treatment, respectively. The hue angle ( $H$ ) and the chroma ( $C$ , intensity) color parameters were calculated using the next equations:

$$H = \tan^{-1}\left(\frac{b}{a}\right) \quad C = \sqrt{(a)^2 + (b)^2}$$

## 2.6 Phenolic compounds

Phenolic compounds in pitaya juice were determined using the Gao, Ohlander, Jeppsson, Bjork & Traljkovski (2000) method with modifications. Two mL of distilled water were placed in an amber glass tube; then, 200  $\mu$ L of the Folin and Ciocalteu's phenol reagent (Sigma-Aldrich, Toluca, Mexico) and 100  $\mu$ L of pitaya juice were added. Mixture was totally homogenized and then incubated for 3 minutes at room temperature (25 °C). Afterward, 1 mL of 20% (p/v)  $\text{Na}_2\text{CO}_3$  was added and thoroughly mixed. This blend was incubated for 1 hour at room temperature in a dark environment. The absorbance was measured at 765 nm using an UV-visible spectrophotometer model 2800 H (UNICO, NJ, EUA). The calculation of the content of phenolic compounds was performed using a standard curve of Gallic acid:

$$GA = \left(\frac{A - b}{m}\right) * 100$$

Where  $GA$  is the Gallic acid content (mg Gallic acid/mL),  $A$  is the absorbance of the sample,  $b$  is the intercept (-0.01), and  $m$  is the slope (4.108 abs/mg GA/mL).

## 2.7 Betalains

Betalains were assessed according to the Stintzing, Schieber & Carle (2002) method. Pitaya juice was diluted with McIlvaine buffer (pH 6.5, citrate-phosphate) to obtain absorption values in the range 0.9-1.0. The betanin and indicaxanthin contents were measured at wave lengths of 538 and 480 nm, respectively. The betalains content is the sum of the betanin and indicaxanthin contents and was calculated according to the next equation:

$$CB = \frac{A * DF * M * 1000}{\epsilon * l}$$

Where  $CB$  is the betalains content (mg/L),  $A$  is the absorbance,  $DF$  is the dilution factor,  $l$  is the quartz cell pathway (1 cm),  $\epsilon$  is the molar extinction coefficient (for  $\epsilon_{\text{betanin}}$  is 60,000 mole/L cm, and for  $\epsilon_{\text{indicaxanthin}}$  is 48,000 mole/L cm), and  $M$  is the molecular weight (550 and 308 g/mole for betanin and indicaxathin, respectively).

## 2.8 Antioxidant activity

The antioxidant activity in juice was determined according to the Kuskoski, Asuero, Parrilla, Troncoso, & Fett (2004) methodology. The  $\text{ABTS}^+$  radical was formed placing 5 mL of distilled water, 3.3 mg of potassium persulfate, and 19.4 mg of the ABTS reagent into an amber glass flask. Reagents were totally mixed and let stand for 16 hours in a dark environment. Afterward, absolute ethanol was mixed with the  $\text{ABTS}^+$  radical ( $\text{ABTS}^+$  radical solution) until reaching an absorbance of  $0.70 \pm 0.02$  at 754 nm. Eighty  $\mu$ L of pitaya juice were mixed with 3,920 L of the  $\text{ABTS}^+$  radical solution, totally mixed and the initial absorbance measure ( $A_i$ ). Mixture was let react for 7 minute and the final absorbance measured ( $A_f$ ). The amount of the antioxidant activity was calculated using the trolox (T) standard curve as follow:

$$UI = \frac{A_i - A_f}{A_i} * 100$$

$$UT = \frac{UI - b}{m} * 100$$

Where  $UT$  is the amount of trolox (mg T/mL),  $UI$  is the percentage of inhibition,  $b$  is the intercept(3.52) and  $m$  is the slope (371.5 abs/mg T/mL).

### 2.9 Total counts

Aerobic mesophyll bacteria (AMB) and molds plus yeasts (MY) were counted using the standard plate count agar and the acidified (10% tartaric acid) potato dextrose agar, respectively. Petri plates for the AMB were incubated in an oven at  $35 \pm 2$  °C and the number of colony forming units per mL (CFU/mL) were counted in a period of 24-48 hours, while the petri plates for the ML were incubated during 5 days at  $25 \pm 2$  °C.

### 2.10 Mathematical modeling

The decimal reduction time ( $D_{uv}$ ) values were calculated using the first-order kinetics model for the survivors in pitaya juice after the UV-C light treatment (Stermer, Lasater-Smith & Brasington, 1987) as follow:

$$\text{Log} \left( \frac{N_t}{N_o} \right) = -kIt = -kF = -kD$$

$$D = F = I * t$$

$$D_{UV} = -\frac{1}{k}$$

Where  $N_t$  is the survivors microbial load (CFU/mL) after UV-C light treatment,  $N_o$  is the initial microbial load (CFU/mL),  $k$  is the inactivation constant rate ( $\text{min}^{-1}$  or  $\text{m}^2/\text{kJ}$ ),  $F = D$  is the dose or fluence ( $\text{kJ}/\text{m}^2$ ),  $I$  is the intensity of the UV-C lamp ( $\text{W}/\text{m}^2$ ), and  $D_{uv}$  is the decimal reduction time required to inactivate 90% of the microorganisms at constant dose or fluence.

### 2.11 Statistical analysis

All results were evaluated by analysis of variance (ANOVA) using the Minitab 14 program (Minitab Inc., PA, USA). A  $p$  value of 0.05 was used for deciding significant differences among averages according to the Turkey's test.

## 3. Results and Discussion

### 3.1 Juice characteristics

Table 1 presents the physicochemical and antioxidant characteristics of fresh pitaya juice. The total soluble solids (Bx) content was lower than that reported for other types of pitayas. Luna (2006) reported values of total soluble solids in the range 10-17.25% (w/w). pH and phenolic compounds content in pitaya juice were similar to those reported for cacti fruits (Nurliyana, Syed, Mustapha, Aisyah & Kamarul, 2010) other than pitaya. Ochoa & Guerrero (2012) reported a phenolic compounds content of  $42.01 \pm 8.06$  mg of GA/100 mL of red prickly pear juice. Nurliyana *et al.* (2010), on the other hand, reported values of 3.75-36.12 mg of GA/100 g of pitaya pulp. The content of betalains in pitaya juice was higher than the amount reported for other red-pigmented fruits (Repo de Carrasco & Encina 2008; Castellanos & Yahia, 2008). This may probably explain the high antioxidant activity found in pitaya juice.

It can also be observed that the  $L$  color parameter indicates that juice is dark in lightness. The  $a$  value is in the red side and the  $b$  value is in the blue side of the color space chart. Pitaya juice has a dark red-purple color; this was corroborated by the hue value which is in the red color side of the color space chart. This could be probably because pitaya juice contains a higher amount of betanin (red-purple color) than indicaxanthin (yellow-orange color). The value of chroma (intensity) indicates that pitaya juice has an intense dark red-purple color.

### 3.2 UV-C light effect on pitaya juice

#### 3.2.1 Physicochemical characteristics

Neither pH nor total soluble solids of pitaya juice were significantly affected ( $P > 0.05$ ) by the UV-C light at the selected flow rates and treatment times. The average values of the total soluble solids and pH, after UV-C light

treatment, were  $6.79 \pm 0.04$  and  $5.93 \pm 0.07$  %, respectively. A number of researchers have reported that UV-C light did not have effect on pH, total soluble solids, and titratable acidity of fruit juices (Noci, Riener, Walkling, Cronin, Morgan & Lying, 2008; Caminiti *et al.*, 2010; Pala & Toklucu, 2011).

### 3.2.2 Color

Table 2 presents the  $L$ ,  $a$ ,  $b$ , and  $\Delta E$  color parameters of pitaya juice treated with UV-C light for 25 minutes. It is observed that the UV-C light significantly affected ( $P < 0.05$ ) color parameters at different flow rates. The higher the flow rate, the lower the change in color of pitaya juice. When comparing the lowest (0.46 mL/s) and highest (30.33 mL/s) flow rates, the highest flow rate make the least change in color of pitaya juice. Guerrero-Beltrán, Welti-Chanes, & Barbosa-Cánovas (2009) reported that increasing the flow rate, for treating grape juice with UV-C light, a lower contact between UV-C light and the liquid food product may occur; therefore, juice could be less affected in its color parameters. Moreover, although data are not presented here, no effect of UV-C light was observed on the color of pitaya juice when increasing treatment time. This could be probably due to the relationship between retention time and flow rate; therefore, further damage to pigments in juice at low flow rates may occur. However, this change in color is too small to make it visible to the naked eye.

### 3.2.3 Phenolic compounds

Figure 1 presents the phenolic compounds content in UV-C light treated pitaya juice. The phenolic compounds content significantly decreased ( $P < 0.05$ ) as the UV-C light processing time increased. However, no effect ( $P > 0.05$ ) was observed regarding the phenolic compounds content when increasing flow rates to treat pitaya juice in the UV-C light system. The reduction of phenolic compounds could be due to the UV-C light effect on the structure of phenolics (Koutchma, 2009). Piga, Del Caro, Pinna, & Agabbio (2003) and Bakowska, Kucharska, & Oszmianski (2003) pointed out that phenolic compounds may protect pigments, ascorbic acid, and antioxidant activity in fruits and juices against environmental injuries. Pala & Toklucu (2011) treated pomegranate juice with UV-C light in a flow range of 12.5 to 62.4 J/mL. They reported no significant differences ( $P > 0.05$ ) in the phenolic compounds content of the UV-C light treated, heat processed, and fresh pomegranate juices. Caminiti *et al.* (2010) also reported that the content of phenolic compounds in apple juice was not affected by the UV-C light when juice was treated at 5.31 and 53.10 J/cm<sup>2</sup> during 30 and 300 s, respectively. Noci *et al.* (2008) reported that phenolic compounds decreased in apple juice treated with UV-C light during 30 minutes. However, their experiment consisted in exposing 800 mL of juice, in a Pyrex plate (25 mm in diameter), to the light of an UV-C mercury lamp (30 W) placed at a distance of 30 cm on top of the juice.

### 3.2.4 Betalains

Figure 2 presents the betalains content in pitaya juice processed with UV-C light. It is observed that increasing flow rates and treatment times significantly decreased ( $P < 0.05$ ) the betalains content; the betalains reduction ranged 3.89-20.21%. This betalains reduction could be probably due to the photons produced by UV-C light. Photons could be absorbed by organic molecules such as betalains which possess conjugated bonds and aromatic rings responsible for color (Woo, Ngou, Ngo, Soong & Tang, 2011; Koutchma, 2009). Guerrero-Beltrán *et al.* (2009) reported that long periods of UV-C light to treat fruit products may undergo discoloration reactions of the pigments. Bakowska *et al.* (2003) reported that phenolic compounds may act as inhibitors of the degradation of anthocyanins during the exposition of fruit and, or vegetable products to the UV-C light. Likely, phenolic compounds might protect pitaya betalains for short periods of time. Pala & Toklucu (2011) reported that the anthocyanins content of pomegranate juice decreased gradually with increasing the UV-C light dose; they reported a decrease in the anthocyanin content of 1.8, 3.9, and 8.4% at UV-C exposure doses of 12.5, 34.4, and 62.4 J/mL, respectively.

### 3.2.5 Antioxidant activity

Figure 3 presents the antioxidant activity in pitaya juice treated with UV-C light. Substantial antioxidant activity was expected since phenolic compounds and betalains may function as antioxidants. The antioxidant activity was reduced by the UV-C light at both treatment times and flow rates. The antioxidant activity decreased significantly ( $P < 0.05$ ) in juice as processing time increased. However, no significant differences ( $P > 0.05$ ) were observed in the antioxidant activity content within flow rates. Caminiti *et al.* (2010) pointed out that the antioxidant activity decreased as the UV-C dose was increased for processing apple juice; however, Pala & Toklucu (2011) reported no significant difference in the antioxidant activity content in fresh and UV-C light treated pomegranate juice using different doses.

It has been reported that UV-C light may affect compounds with high antioxidant activity. For example, Sabliov, Fronczek, Astete, Khachatryan, Khachatryan & Leonardi (2009) reported that the initial content of  $\alpha$ -tocopherol,

dissolved in hexane or methanol, was significantly reduced when increasing the UV-C light treatment. Cvetkovic, Markovic, Cvetkovic & Radovanovic (2011), on the other hand, reported that UV-A, UV-B, and UV-C may reduce the antioxidant activity of phenolic compounds such as rutin and quercetin; the damage of these compounds was increased as the UV-C exposure time was increased. They pointed out that the reduction of compounds with antioxidant activity could be due to the combination of UV-C light and oxygen.

### 3.2.6 Microbial inactivation

Figures 4 and 5 present the aerobic mesophyll bacteria and molds plus yeasts in the UV-C light treated pitaya juice, respectively. The number of colony forming units per milliliter, in both types of microorganisms, decreased as the flow rate and treatment time increased. Pitaya juice possesses a dark red-purple color and this could avoid the penetration of light; however, turbulence regime, formed by increasing the speed, is enough for making all the liquid be in contact with the UV-C light and obtain a greater microbial inactivation (Li, Deng & Nyung, 2010). Caminiti *et al.* (2010) and Guerrero-Beltrán & Barbosa-Cánovas (2005) pointed out that the transparency and soluble and insoluble solids of the liquid food product, or medium, are critical factors in the microbial inactivation with UV-C light; both color and turbidity may block the pathway of light and prevent microorganisms to be reached by the UV-C light. Li *et al.* (2010) reported that the penetration of UV-C light in the product is of utmost importance since better results, regarding microbial inactivation, are obtained on the surface of the food. Recent investigations have been performed to explore the effect of UV-C light in the inactivation of microorganisms inoculated in different fruit juices. Guerrero-Beltrán & Barbosa-Cánovas (2005) and Guerrero *et al.* (2009) reported a log reduction of  $1.34 \pm 0.35$  and 1.3 for *S. cerevisiae* inoculated in apple and grape juice, respectively. These results agree with those obtained in this research for yeasts plus molds in pitaya juice.

Table 3 presents the microbial counts and the log reductions for AMB and MY for the selected flow rates after 25 minutes of UV-C light treatment of pitaya juice. It can be observed that the AMB load is higher than the MY load; however, both types of microorganisms were reduced by the UV-C light. Li *et al.* (2010) pointed out that the efficiency of the UV-C light effect on microorganisms is a function of the initial microbial load. It is also observed that the higher the flow rate, the higher the inactivation effect for both types of microorganisms. The greater inactivation for AMB (2.11 log cycles reductions) and MY (1.14 log cycles reductions) was reached after 25 min of UV-C light treatment. This could be because bacterial cells are smaller than molds and yeasts; therefore, bacteria could be more easily reached and compromised by the UV-C light (Montgomery, 1985). In addition, bacterial cells are constituted by large levels of pyrimidine in the DNA; this may increase the probability of generating more cross-linkages between thymine and cytosine (Torkamani & Niakousari, 2011) by the UV-C light. Oteiza, Giannuzzi & Zaritzky (2010) reported that orange juice, inoculated with *S. cerevisiae*, decreased the ability of UV-C light for inactivating five *E. coli* O157: H7 strains. They concluded that yeasts, due to their size, increased the coefficient of absorption of the UV-C light. Therefore, high doses might be required to obtain the same inactivation effect on the *E. coli* strains. López-Malo, Guerrero, Santiesteban & Alzamora (2005) processed apple juice, inoculated with *L. monocytogenes* and *S. cerevisiae*, with UV-C light. They reported that bacteria are more sensitive ( $> 5$  log reduction) than yeasts (4 log reductions) to UV-C light.

Table 4 presents the first-order kinetics parameters for the AMB and MY inactivation in pitaya juice treated with UV-C light. The first order kinetics representation provided good fittings of the inactivation ( $R^2 > 0.95$ ) of AMB. This representation is not entirely appropriate for MY.  $D_{uv}$  values decreased as flow rates increased, this means that the inactivation of the microbial load increased as flow rate increased. Guerrero-Beltrán & Barbosa-Cánovas (2005) reported  $D_{uv}$  values of 5.9, 7.0, and 22.4 minutes for *E. coli*, *L. innocua*, and *S. cerevisiae* inactivation in apple juice treated with UV-C light at a flow rate of 9.13 mL/s. Torkamani & Niakosari (2011), on the other hand, reported  $D_{uv}$  values of 0.82 and 1.05 kJ/m<sup>2</sup> for total counts and yeasts plus molds, respectively, in not inoculated orange juice. Both sets of values are similar to those found in this study for same types of microorganisms.

## 4. Conclusions

The use of UV-C light to treat pitaya juice is a feasible alternative to deliver a microbiologically safe juice to consumers. Despite of not accomplish the 5 log reductions required by the FDA, pitaya juice maintains its quality because other physicochemical attributes remained barely unchanged. The decline in the quality attributes of pitaya juice is mainly a function of time or dose of treatment with the UV-C light. Maximum log cycle reductions of 2.11 and 1.14 for AMB and MY, respectively, were obtained after 25 minutes of UV-C light treatment at a flow rate of 30.33 mL/s. Under these conditions of treatment, changes in color were practically non-existent compared to fresh juice. The phenolic compounds, antioxidant activity, and betalains content

decreased by 13.27, 3.55, and 26.02%, respectively, in comparison to the content in fresh juice. It is important to take into account that the actual effect of the UV-C light on microbial inactivation in pitaya juice may depend on the UV-C dose used to treat juice as well as the type and amount of microorganisms.

## References

- AOAC. (2000). Official methods of analysis. 14<sup>th</sup> ed., *Association of Official Analytical Chemists*. Washington, DC, USA.
- Ayala, K., Beltrán, C., & Cruz, T. (2007). Determinación de la actividad enzimática de extractos crudos de cuatro variedades de pitaya *Stenocereus griseus*H. In *XII Congreso Nacional de Biotecnología y Bioingeniería*, 25-29.
- Bakowska, A., Kucharska, A. Z., & Oszmianski, J. (2003). The effects of heating, UV irradiation, and storage on stability of the anthocyanin-polyphenol copigment complex. *Food Chemistry*, 81, 349-355. [http://dx.doi.org/10.1016/S0308-8146\(02\)00429-6](http://dx.doi.org/10.1016/S0308-8146(02)00429-6)
- Barka, E. A., Kalantari, S., Makhlof, J., & Arul, J. (2000). Impact of UV-C irradiation on the cell wall-degrading enzymes during ripening tomato (*Lycopersicon esculentum* L) fruit. *Journal of Agricultural and Food Chemistry*, 48, 667-671. <http://dx.doi.org/10.1021/jf9906174>
- Begum, M., Hocking-Ailsa, D., & Miskelly, D. (2009). Inactivation of food spoilage fungi by ultra violet (UVC) irradiation. *International Journal of Food Microbiology*, 129(1), 74-77. <http://dx.doi.org/10.1016/j.ijfoodmicro.2008.11.020>
- Caminiti, I., Palgan, I., Muñoz, A., Noci, F., Whyte, P., Morgan, D., Cronin, D., & Lyng, J. (2010). The effect of ultraviolet light on microbial inactivation and quality attributes of apple juice. *Food Bioprocess Technology*. <http://dx.doi.org/10.1007/s11947-010-0365-x>.
- Castellanos, E., & Yahia, E. M. (2008). Identification and quantification of betalains from the fruits of 10 Mexican prickly pear cultivars by high performance liquid chromatography and electrospray ionization mass spectrometry. *Journal of Agricultural and Food Chemistry*, 56, 5758-5764. <http://dx.doi.org/10.1021/jf800362t>
- Cvetkovic, D., Markovic, D., Cvetkovic, D., & Radovanovic, B. (2011). Effects of continuous UV-irradiation on the antioxidant activities of quercetin and rutin in solution in the presence of lecithin as the protective target. *Journal of the Serbian Chemical Society*, 76(7), 973-985. <http://dx.doi.org/10.2298/JSC101123089C>
- Falguera, V., Pagán, J., & Ibarz, A. (2011). Effect of UV irradiation on enzymatic activities and physicochemical properties of apple juices from different varieties. *LWT - Food Science and Technology*, 44, 115-119. <http://dx.doi.org/10.1016/j.lwt.2010.05.028>
- FDA. (2000). 21 CFR Part 179. Irradiation in the production, processing and handling of food. *Federal Register*, 65, 71056-71058.
- FDA. (2001). Hazard Analysis and Critical Point (HACCP); Procedures for the safe and sanitary processing and importing of juice; Final rule. *Federal Register*, 66, 6137-6202.
- Gabriel, A., & Nakano, N. (2009). Inactivation of *Salmonella*, *E. coli* and *Listeria monocytogenes* in phosphate-buffered saline and apple juice by ultraviolet and heat treatments. *Food Control*, 20, 443-446. <http://dx.doi.org/10.1016/j.foodcont.2008.08.008>
- Gao, X., Ohlander, M., Jeppsson, N., Bjork, L., & Traljkovski, V. (2000). Changes in antioxidant effects and their relationship to phytonutrients in fruits of sea L. (*Hippophae rhamnoides*L) during maturation Buckthorn. *Journal of Agricultural and Food Chemistry*, 48, 1485-1490. <http://dx.doi.org/10.1021/jf991072g>
- Guerrero-Beltrán, J. A., & Barbosa-Cánovas, G. V. (2004). Advantages and limitations on processing foods by UV light. *Food Science and Technology International*, 17(1), 137-147.
- Guerrero-Beltrán, J. A., & Barbosa-Cánovas, G.V. (2005). Reduction of *Saccharomyces cerevisiae*, *Escherichia coli* and *Listeria innocua* in apple juice by ultraviolet light. *Journal of Food Process Engineering*, 28, 437-452. <http://dx.doi.org/10.1111/j.1745-4530.2005.00040.x>
- Guerrero-Beltrán, J. A., & Barbosa-Cánovas, G. V. (2006). Inactivation of *Saccharomyces cerevisiae* and polyphenoloxidase in mango nectar treated with UV light. *Journal of Food Protection*, 69(2), 362-368.
- Guerrero-Beltrán, J. A., Welti-Chanes, J. S., & Barbosa-Cánovas, G. V. (2009). Ultraviolet-C light processing of grape, cranberry and grapefruit juices to inactivate *Saccharomyces cerevisiae*. *Journal of Food Process Engineering*, 32(6), 916-932. <http://dx.doi.org/10.1111/j.1745-4530.2008.00253.x>
- Ibarz, A., & Barbosa-Cánovas, G. V. (2002). Thermal processing of foods. In A. Ibarz, & G. V. Barbosa-Cánovas (Eds.), *Unit Operations in Food Engineering* (491-534), Washington: CRC Press.

- Keyser, M., Muller, I. A., Cilliers, F. P., Nel, W., & Gouws, P. A. (2008). Ultraviolet radiation as a non-thermal treatment for the inactivation of microorganisms in fruit juice. *Innovative Food Science & Emerging Technologies*, 9(3), 348–354. <http://dx.doi.org/10.1016/j.ifset.2007.09.002>
- Koutchma, T. (2009). Advances in ultraviolet light technology for non-thermal processing of liquid foods. *Food and Bioprocess Technology*, 2(2), 138–155. <http://dx.doi.org/10.1007/s11947-008-0178-3>
- Kuskoski, M., Asuero, A., Parrilla, M., Troncoso, A., & Fett, R. (2004). Actividad antioxidante de pigmentos antocianicos. *Ciencia y Tecnología de Alimentos (Campinas, Brazil)*, 24, 691-693.
- Li, C., Deng, B., & Nyung, C. (2010). A numerical prediction on the reduction of microorganisms with UV disinfection. *Journal of Mechanical Science and Technology*, 24(7), 1465-1473. <http://dx.doi.org/10.1007/s12206-010-0502-5>
- López-Malo, A., Guerrero, S. N., Santiesteban, A., & Alzamora, S. M. (2005). Inactivation kinetics of *Saccharomyces cerevisiae* and *Listeria monocytogenes* in apple juice processed by novel technologies. In *2<sup>nd</sup> Mercosur Congress on Chemical Engineering, 4<sup>th</sup> Mercosur Congress on Process Systems Engineering*, Rio de Janeiro, Brazil, August, 14-18.
- Lu, G., Li, C., Liu, P., Cui, H., Xia, Y., & Wang, J. (2010). Inactivation of microorganisms in apple juice using an ultraviolet silica-fiber optical device. *Journal of Photochemistry and Photobiology B: Biology*, 100, 167-172. <http://dx.doi.org/10.1016/j.jphotobiol.2010.06.003>
- Luna, C. (2006). Clasificación y ordenación morfológica del fruto de variantes cultivadas de pitaya [*Stenocereus Prinosus* (otto) Buxb.] en la Mixteca baja, México. *Revista Chapingo Serie Horticultura*, 12(2), 245-251.
- Montgomery, J. M. (1985). *Water treatment: Principles and design*. New York: John Wiley and Sons.
- Noci, F., Rieneer, J., Walkling, M., Cronin, D. A., Morgan, D. J., & Lying, J. G. (2008). Ultraviolet irradiation and pulsed electric fields (PEF) in a hurdle strategy for the preservation of fresh apple juice. *Journal of Food Engineering*, 85, 141-146. <http://dx.doi.org/10.1016/j.jfoodeng.2007.07.011>
- Nurliyana, R., Syed, I., Mustapha, K., Aisyah, M. R., & Kamarul, K. (2010). Antioxidant study of pulps and peels of dragon fruits: a comparative study. *International Food Research Journal*, 17, 367-375.
- Ochoa, C. E., & Guerrero, J. A. (2012). Efecto del almacenamiento a diferentes temperaturas sobre la calidad de tuna roja (*Opuntia ficus indica* (L.) Miller). *Información Tecnológica*, 23(1), 117-128.
- Oteiza, J., Giannuzzi, L., & Zaritzky, N. (2010). Ultraviolet treatment of orange juice to inactivate *E. coli* O157:H7 as affected by native microflora. *Food and Bioprocess Technology*, 3(4), 603-614. <http://dx.doi.org/10.1007/s11947-009-0194-y>
- Pala, C., & Tochluku, A. (2011). Effect of UV-C light on anthocyanin and other quality parameters of pomegranate juice. *Journal of Food Composition and Analysis*, 24(6), 790-795. <http://dx.doi.org/10.1016/j.jfca.2011.01.003>
- Piga, A., Del Caro, A., Pinna, I., & Agabbio, M. (2003). Changes in ascorbic acid, polyphenol content and antioxidant activity in minimally processed cactus pear fruits. *Lebensmittel-Wissenschaft und-Technologie*, 36, 257-262.
- Quek, P., & Hu, J. (2008). Indicators for photoreactivation and dark repair studies following ultraviolet disinfection. *Journal of Industrial Microbiology and Biotechnology*, 35, 533-541. <http://dx.doi.org/10.1007/s10295-008-0314-0>
- Repo de Carrasco, R., & Encina, C. (2008). Determinación de la capacidad antioxidante y compuestos bioactivos de frutas nativas peruanas. *Revista de la Sociedad Química del Perú*, 74(2), 108-124.
- Sabliov, C., Fronczek, C., Astete, C., Khachatryan, M., Khachatryan, L., & Leonardi, C. (2009). Effects of temperature and UV light on degradation of  $\alpha$ -tocopherol in free and dissolved form. *Journal of the American Oil Chemists Society*, 86, 895-902. <http://dx.doi.org/10.1007/s11746-009-1411-6>
- Stermer, R. A., Lasater-Smith, M., & Brasington, C. F. (1987). Ultraviolet radiation an effective bactericide for fresh meat. *Journal of Food Protection*, 50(2), 108-111.
- Stintzing, F. C., Schieber, A., & Carle, R. (2002). Identification of betalains from yellow beet (*Beta vulgaris* L.) and cactus pear (*Opuntia ficus-indica* (L.) Mill) by HPLC-electrospray ionization mass spectrometry. *Journal of Agricultural and Food Chemistry*, 50, 2302-2307. <http://dx.doi.org/10.1021/jf011305f>
- Torkamani, A. E., & Niakousari, M. (2011). Impact of UV-C light on orange juice quality and shelf life. *International Food Research Journal*, 18(4), 1265-1268.

Woo, K., Ngou, F., Ngo, L., Soong, W., & Tang, P. (2011). Stability of betalain pigment from red dragon fruit (*Hylocereus polyrhizus*). *American Journal of Food Technology*, 6(2), 140-148. <http://dx.doi.org/10.3923/ajft.2011.140.148>.

Table 1. Physicochemical and antioxidant characteristics of fresh pitaya (*Stenocereus griseus*) juice

Characteristic		Quantity
Total soluble solids (%)		6.75±0.08
pH		5.91±0.08
Color	<i>L</i>	30.52±0.10
	<i>a</i>	61.91±0.65
	<i>b</i>	18.78±0.06
	Hue	16.87±0.08
	Chroma	64.13±0.13
Phenolic compounds (mg GA/100 mL)		39.00±0.09
Betalains	Betanin (mg/L)	61.05±2.22
	Indicaxanthin (mg/L)	52.48±0.18
Antioxidant activity (mg de T/100 mL)		100.60±1.17

Table 2. Color parameters of pitaya juice after 25 min of UV-C light treatment<sup>1</sup>

Color parameters				
Flow rate (mL/s)	<i>L</i>	<i>a</i>	<i>b</i>	ΔE
0.00	30.52±0.10 <sub>a</sub>	61.91±0.65 <sub>a</sub>	18.78±0.06 <sub>a</sub>	0.00 <sub>a</sub>
0.46	28.26±0.14 <sub>b</sub>	58.16±0.14 <sub>b</sub>	17.50±0.07 <sub>b</sub>	3.38 <sub>b</sub>
3.28	29.27±0.08 <sub>c</sub>	59.88±0.16 <sub>c</sub>	18.21±0.06 <sub>c</sub>	1.63 <sub>c</sub>
6.57	29.47±0.10 <sub>c</sub>	59.67±0.12 <sub>c</sub>	18.31±0.08 <sub>c</sub>	1.70 <sub>c</sub>
16.49	28.57±0.08 <sub>d</sub>	58.68±0.09 <sub>d</sub>	17.63±0.08 <sub>d</sub>	2.88 <sub>d</sub>
30.33	30.43±0.04 <sub>a</sub>	62.22±0.14 <sub>a</sub>	18.67±0.04 <sub>a</sub>	0.87 <sub>a</sub>

<sup>1</sup>: Same litters within columns indicate no significant differences ( $P > 0.05$ ).

Table 3. Log cycles reduction for aerobic mesophyll bacteria and yeasts plus molds in UV-C light treated pitaya juice for 25 minutes

Flow rate (mL/s)	Aerobic mesophyll bacteria		Yeasts plus molds	
	(CFU/mL) ( $\times 10^{-3}$ )	log ( <i>N/N</i> <sub>0</sub> )	(CFU/mL)	log ( <i>N/N</i> <sub>0</sub> )
0.00	38.0±0.079	0	850±21	0
0.46	18.0±0.079	-0.33	630±57	-0.12
3.28	12.0±0.078	-0.52	460±35	-0.27
6.57	9.6±0.020	-0.6	430±14	-0.29
16.49	1.0±0.014	-1.58	165±21	-0.71
30.33	0.5±0.028	-2.11	62±11	-1.14

Table 4. First order kinetics data from the aerobic mesophyll bacteria and yeasts plus molds inactivation in UV-C light treated pitaya juice

Flow rate (mL/s)	Aerobic mesophyll bacteria					Yeasts plus molds				
	m (1/min)	b	R <sup>2</sup>	D <sub>uv</sub> (min)	D <sub>uv</sub> (kJ/m <sup>2</sup> )	m (1/min)	b	R <sup>2</sup>	D <sub>uv</sub> (min)	D <sub>uv</sub> (kJ/m <sup>2</sup> )
0	--	--	--	--	--	--	--	--	--	--
0.46	-0.013	0.005	0.97	80.1	2.74	-0.003	-0.042	0.50	375	12.8
3.28	-0.022	0.022	0.98	46.7	1.59	-0.012	0.019	0.93	87.1	2.98
6.57	-0.025	0.031	0.99	40.8	1.39	-0.011	0.049	0.75	101	3.45
16.49	-0.068	0.175	0.98	14.9	0.51	-0.029	0.014	0.89	35.9	1.23
30.33	-0.073	-0.130	0.96	13.9	0.47	-0.04	-0.26	0.91	23.5	0.80

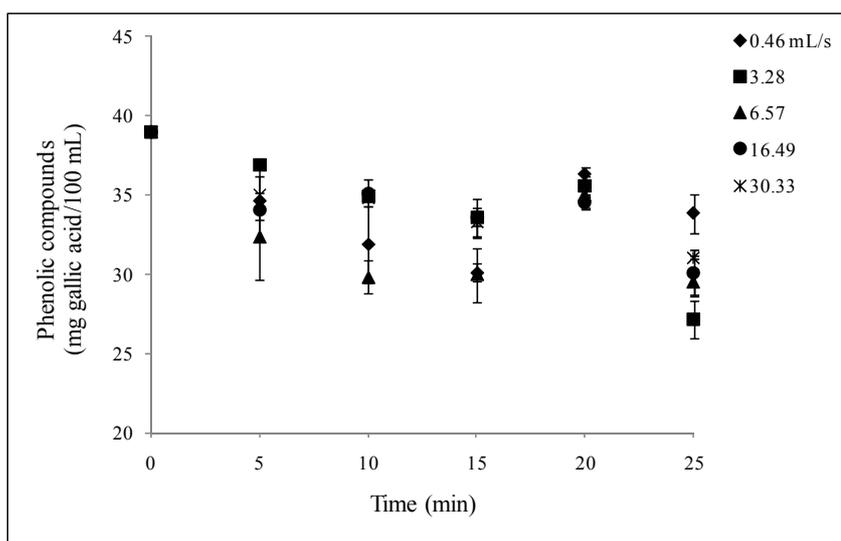


Figure 1. Phenolic compounds in UV-C light treated pitaya juice

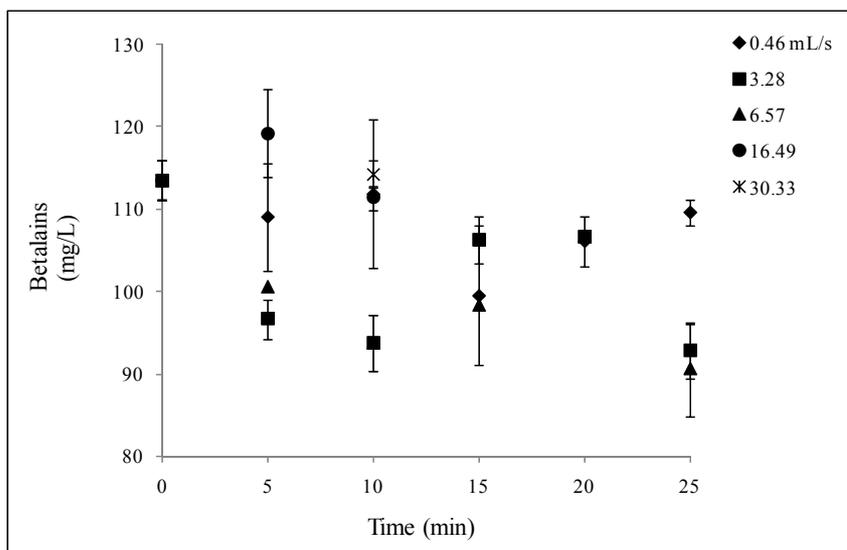


Figure 2. Betalains content in UV-C light treated pitaya juice

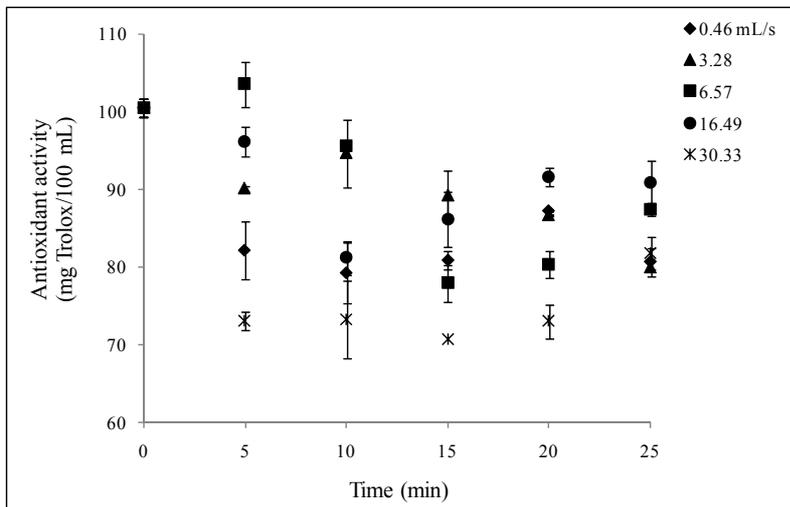


Figure 3. Antioxidant activity in UV-C light treated pitaya juice

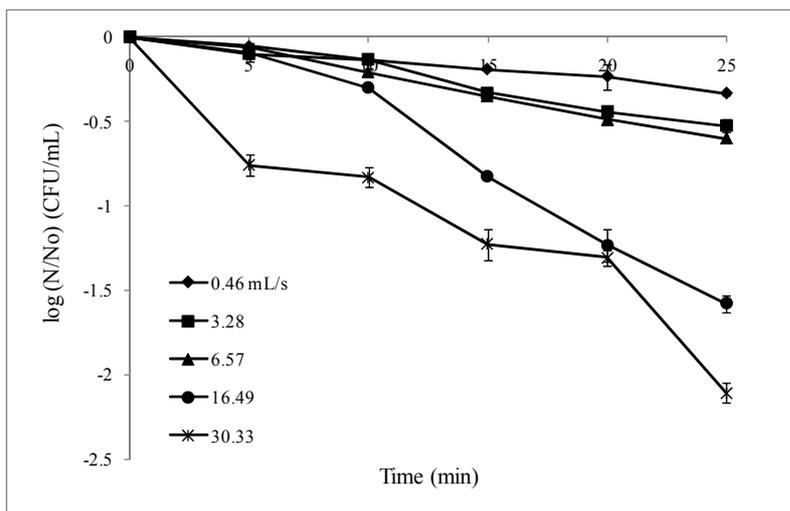


Figure 4. Aerobic mesophyll bacteria in UV-C light treated pitaya juice

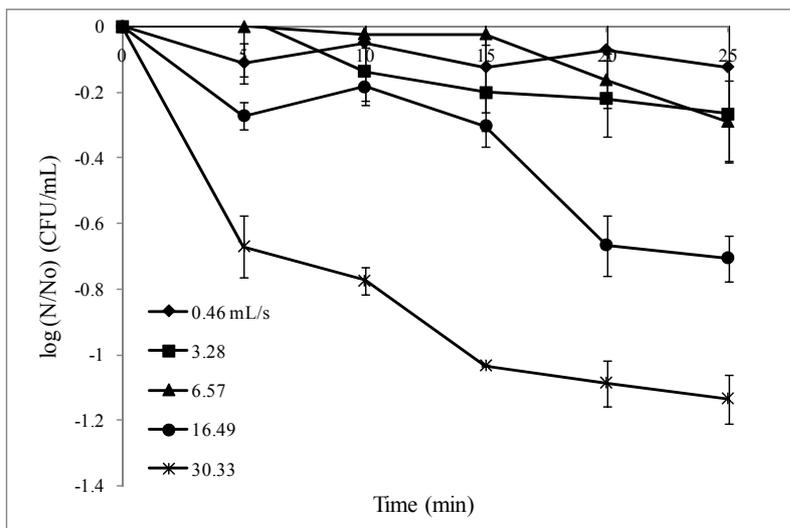


Figure 5. Molds plus yeasts in UV-C light treated pitaya juice