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Effects of ultraviolet-C treatment in Teflon®-coil on microbial populations and physico-chemical characteristics of watermelon juice

Mei Feng [a], Kashif Ghafoor [b], Bohyun Seo [a], Keunyong Yang [a], Jiyong Park [a,*]

[a] Department of Biotechnology, College of Life Science and Biotechnology, Yonsei University, Seoul 120-749, Republic of Korea
[b] Department of Food Science and Nutrition, College of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia

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ABSTRACT

The efficacy of UVC radiation for inactivation of bacteria (aerobic, coliform) and yeast/mold in watermelon juice using helix Teflon®-coil was investigated. Changes in microbial load, pH, °brix, color (L*, a*, and b*), lycopene, and phenolics in juice, after UVC treatment were evaluated for 37 days of storage at 5 ± 1 °C. Microbial inactivation was dependent on the UVC intensity between 2.7 and 37.5 J/mL. UVC treatment inactivated all (2.6 log CFU/mL) coliform bacteria. UVC (37.5 J/mL) reduced total aerobes and yeast/mold by 1.47 and 0.99 log CFU/mL, respectively. The microbial load in treated juice remained lower than 6.0 log CFU/mL until the 31st day of storage. UVC treatment resulted in no-significant effects on pH, °brix, color change, lycopene, and phenolics, the values of which remained consistent with those of a control until 25th day of storage. UVC treated juice had lower b* (yellowness) and higher a* (redness) colors than untreated juice.
Industrial relevance: Watermelon juice is a potential health food and strategies to increase its shelf-life with minimal or no damage to nutritional components are crucial for obtaining more commercial benefits. Our study suggests that a Teflon®-coil UVC system can be effectively used as a non-thermal method for microbial inactivation in watermelon juice and to improve the product shelf-life with no significant effects on different physico-chemical and nutritional characteristics.

1. Introduction

Watermelon, an exotic fruit containing antioxidants with reported health benefits, is an important source of lycopene and contains 40% more lycopene (per 100 g) than raw ripe red tomatoes (Peabody, 2007). Watermelon can be a constituent of a sensible diet low in sodium, saturated fat, and cholesterol. Lycopene, a type of carotenoid, is responsible for the red color in fruits and vegetables and the consumption of foods containing lycopene has been associated with a reduced incidence of coronary heart disease and some types of cancer (Oms-Oliu, Odriozola-Serrano, Soliva-Fortuny, & Martín-Belloso, 2009). As consumers and manufacturers realize the health benefits of watermelon, this juice has the potential to become a popular fruit drink. Watermelon juice can be found in many bars as a mixer for alcoholic beverages. Although fresh watermelon juice can be a preferred product, pathogenic microorganisms can grow if the juice is not processed, the reason being low acidity and a high water activity (Liu, Hu, Zhao, & Song, 2012). Therefore, pasteurization can be considered as necessary for a safe juice product. Thermal treatment is a traditional and effective method for the purpose of destroying pathogenic microorganisms in foods (Lambert, 2003). However, watermelon is a thermo-sensitive fruit; therefore, organoleptic and nutritional properties of the juice will be changed by heat (Zhang et al., 2006). The rising consumer demand for fresh and healthy food products has stimulated research on innovative non-thermal processing technologies. UVC radiation is used as a non-thermal technology for preservation of juices (Koutchma, 2009). UVC radiation in the range of 200–280 nm wavelength has germicidal effects on microorganisms, including bacteria, yeasts, molds, and viruses (Caminiti et al., 2012; Tran & Farid, 2004). UVC radiation is absorbed by the DNA and prevents both transcription and translation because adjacent pyrimidine bases bond to each other on the same DNA strand (Franz, Specht, Cho, Graef, & Stahl, 2009; Koutchma, 2009). Common mercury lamps used as UVC sources have electromagnetic emissions near 254 nm. Absorption of light radiation by foods depends on the wavelength, concentration, and nature of the target substance according to the Lambert–Beer law. Due to a smaller particle size and a lower concentration of dissolved compounds in juices, the depth of radiation penetration is relatively small and most radiation is absorbed within a few millimeters. Therefore, the efficiency of a radiation treatment system is highly dependent on effective process engineering. For this reason we used a helically wound Teflon®-coil to cause a secondary eddy flow. This type of liquid flow leads to secondary vortices, known as 'Dean vortices', that allow radial fluid mixing, even in a laminar flow field, resulting in greater UV exposure for all elements in the fluid (Dean, 1927; Müller, Stahl, Graef, Franz, & Huch, 2011). This is especially important for cloudy juices. Considering this

* Corresponding author. Tel.: +82 2 2123 2888; fax: +82 2 362 7265.
E-mail address: foodpro@yonsei.ac.kr (J. Park).

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important issue, UVC reactors, with different design modifications, have been evaluated for pasteurization of fruit juices (Koutchma, 2009). The inactivation effects of UVC on pathogenic and spoilage microorganisms in apple juice (Caminiti et al., 2012; Franz et al., 2009), orange juice (Tran & Farid, 2004), grape, cranberry, and grapefruit juice (Guerrero-Beltran & Barbosa-Canovas, 2005), strawberry, and mango nectar (Keyser, Müller, Cilliers, Nel, & Gouws, 2008) have been reported. Although the effects of UVC treatment on the sensory traits and some physico-chemical properties of watermelon and different fruit juices (Caminiti et al., 2012; Tran & Farid, 2004; Zhang et al., 2006) have been reported, there is need to study the effects of UVC treatment on microbial inactivation and bioactive compounds during storage of treated watermelon juice. Some studies have also reported UV-assisted degradation of phenolics and lycopene due to oxidation and isomerization (Chen, Shi, Xue, & Ma, 2009). Hence, it is important to study the antimicrobial effects of UVC treatment together with the status of important bioactive compounds.

The main objectives of our study were to treat watermelon juice with UVC radiation of varying intensity in a Teflon®-coil rector for inactivation of bacteria and yeast/mold and to determine changes in microbial loads, pH, °brix, lycopene, phenolics, L*, a*, and b* values, and color parameters of treated juice stored at 5 ± 1 °C.

2. Materials and methods

2.1. Preparation of watermelon juice

Commercially mature watermelons weighing, on an average, 3 kg each were purchased from the Agricultural Cooperative Market in Seoul, Korea. Watermelons were washed, peeled, and cut into small cubes of approximately 2.5 cm. These cubes were squeezed using a juicer (Angelia, Angel Co., Ltd., Busan, Korea). Extracted juice was filtered through six layers of 200-mesh cheese cloth, poured into autoclaved stainless steel cups, placed in an ice bath, and immediately subjected to further treatment.

2.2. Reactor for UVC treatment

The UVC reactor, used for juice treatment (Fig. 1) consisted of either a helically wound polytetrafluoroethylene (PTFE) or Teflon® tube with an internal volume of 160 mL wrapped around a quartz glass tube containing a UVC lamp (254 nm; 75 W output) from Sankyo Denki, Japan. PTFE is a hydrophobic fluorocarbon so neither water nor water-containing substances wet PTFE. The helical configuration of the Teflon®-coil around the lamp and secondary eddy flow effects in the liquid (Dean vortices, also known as the Dean effect) (Dean, 1927; Müller et al., 2011) were intended to ensure that all liquid food samples passed through the UVC zone, providing for effective disinfection. A cool water circulation system was used to control the set temperature and avoid juice heating (Fig. 1). The temperature was maintained at 10 °C in all experiments.

The degree of bacterial inactivation in this system was evaluated at different juice flow rates using a peristaltic pump. The UVC dosage was inversely proportional to the juice flow rate and was determined based on the energy delivered per volume of juice (Keyser et al., 2008). The dosage, expressed as joules per milliliter, was calculated theoretically using Eq. (1) (Geveke, 2008; Keyser et al., 2008):

$$\text{UVC intensity } \left({}^{J}/_{mL}\right) = \frac{\text{Total UVC output power(W)}}{\text{Flow rate (mL/s)}}. \quad (1)$$

Watermelon juice was passed through the reactor at different flow rates based on the corresponding UVC intensity (2.7, 5.4, 9.4, and 37.5 J/mL). Microbial, chemical, and physical analyses followed.

2.3. Packaging and storage

Sterile polypropylene bottles (125 mL) were filled with treated juice directly from the sample outlet of the reactor, leaving no head space in the bottle. Filled bottles were closed and sealed, followed by storage at 5 ± 1 °C for 37 days. Physico-chemical and microbiological analyses of treated and untreated juice samples were carried out after 0, 3, 6, 9, 13, 17, 21, 25, 29, 33, and 37 days of storage.

2.4. Microbial analysis

Watermelon juice was analyzed for total aerobic bacteria and coliforms using Petrifilm™ (3M Company, MN, USA) after serial dilution in 0.85% saline water. Total yeast/mold was enumerated using the pour plate method on potato dextrose agar (Difco Laboratories, MD, USA). The aerobic bacteria and coliform petrifilms were incubated at 37 °C for 48 h and yeast/mold agar plates were incubated at 30 °C for 72 h. Colonies were counted and the microbial population was reported as log CFU/mL.

2.5. Determination of pH and °brix

The pH of watermelon juice was monitored using a pH meter (520A, Thermo Orion, MA, USA). For °brix measurement, approximately 1 mL of watermelon juice was placed on the lens of an automatic refractometer (SMART-1, Atago Co., Tokyo, Japan) and analyzed at 25 °C.

2.6. Determination of color

The color of juice samples was measured using a chromameter with the Hunter color system (Konica CR-400, Minolta Sensing Inc., Tokyo, Japan). The chromameter was calibrated using a white tile (Y = 92.8, x = 0.3160, y = 0.3323). Color values were expressed as L* (lightness or brightness/darkness), a* (redness) and b* (yellowness). Total color change (ΔE) was determined using Eq. (2) and indicates the magnitude of the color change during storage.

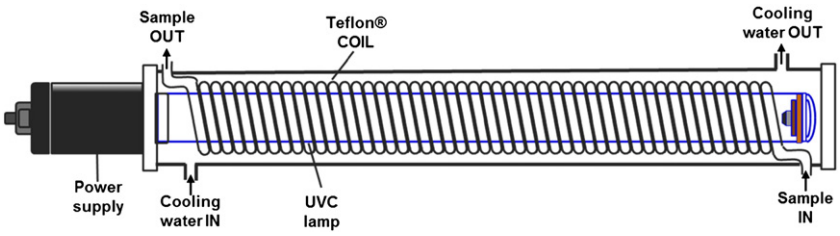

Fig. 1. The Teflon®-coil UVC reactor used for treatment of watermelon juice.

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

where L_0, a_0, and b_0 are color values of untreated juice.

2.7. Determination of total lycopene

The total lycopene content was measured following a previously described spectrophotometeric method (Oms-Oliu et al., 2009). Juice samples (0.6 g) were mixed with 5 mL of 0.05% (w/v) butylatedhydroxytoluene in acetone, 5 mL of 95% USP-grade ethanol, and 10 mL of hexane. The homogenate was centrifuged (320 ×*g*) for 15 min at 4 °C (AG22331, Eppendorf, Hamburg, Germany). After shaking, 3 mL of distilled water was added. Vials were then agitated for 5 min and left at room temperature to allow phase separation. The absorbance (Abs_{503}) of the upper (hexane) layer was measured in a 1 cm path-length quartz cuvette at 503 nm blanked with hexane. The lycopene content (mg/L) of each sample was estimated as follows:

$$\text{Lycopene} = \frac{Abs_{503} \times MW \times DF \times 1000}{\varepsilon \times L} \quad (3)$$

where MW is the molecular weight of lycopene (536.9 g/mol), DF is the dilution factor, L is the path length in cm, and ε is the molar extinction coefficient for lycopene (172,000 L/mol/cm).

2.8. Determination of total phenolic compounds

Total phenolic compounds were determined using the Folin–Ciocalteu method (Ghafoor, Park, & Choi, 2010). Watermelon juice samples were filtered through No. 4 filter paper (Whatman International Ltd., Kent, UK), centrifuged at 11,300 ×*g* for 3 min at 4 °C, then the supernatant was collected. An amount of 20 μL of supernatant, 1.58 mL of distilled water, 100 μL of Folin–Ciocalteu reagent (Sigma Chemical Co., MO, USA), and 300 μL of Na_2CO_3 was added to a 1 cm path-length quartz cuvette (2.5 mL) and then left in the dark for 30 min at 40 °C. The absorbance of the sample was measured at 735 nm. Gallic acid (0–40 mg/mL) was used to construct a standard curve for calibration of analytical results on each day of measurement. The value of the regression coefficient (R^2) of the standard curve was approximately 0.998 each day. Results were calculated as mg of gallic acid equivalent per mL (mg GAE/mL) using the relations generated from the respective calibration curves in which the absorbance value was divided by a certain numerical values generated each time using linear regression.

2.9. Statistical analysis

UVC treatments were carried out in duplicates. All microbial and physico-chemical analyses were carried out in triplicate. Results were expressed as mean ± standard deviation (SD). One-way analysis of variance (ANOVA) and multiple comparisons (Student–Newman–Keuls test) were carried out using Statistical Package for the Social Sciences software (SPSS Version 18, IBM Corporation, NY, USA). The ANOVA test was performed for all experimental runs to determine significance at the 95% confidence interval. Results were considered significant when $P < 0.05$.

3. Results and discussion

3.1. Effects of UVC on total aerobes, coliforms, and yeast/mold in juice

The mean initial populations of total aerobes, coliforms, and yeast/mold in untreated fresh watermelon juice were 2.73, 1.62, and 3.47 log CFU/mL, respectively (Table 1). The microbial counts determined in fresh watermelon juice were similar to results reported for other fruit juices, such as fresh pomegranate juice (Varela-Santos et al., 2012). Immediately after UVC treatments of different intensities (intensity was increased by decreasing the juice flow rate in the Teflon®-coil reactor, as described in Eq. (1)), counts of total aerobes, coliforms, and yeast/mold were found to be significantly ($P < 0.05$) reduced. All coliform bacteria were inactivated, even by a mild (2.7 J/mL) UVC treatment. A 37.5 J/mL UVC treatment resulted in 1.47 and 0.99 log CFU/mL reductions in total aerobes and yeast/mold, respectively while a 9.4 J/mL UVC treatment resulted in respective reductions of total aerobes and yeast/mold by 1.29 and 1.0 log CFU/mL. Microbial inactivation in treated juice samples was mostly dependent on the intensity of the UVC; however, there was no increase in the number of inactivated yeast and mold when the UVC intensity was increased from 9.4 to 37.5 J/mL. UVC radiation is routinely used in the food industry for inhibiting microbial growth on surfaces, in air, and in liquids and is most effective for germicidal purposes at 254 nm (UVC) since energy at that wavelength can induce formation of pyrimidine dimers that distort the DNA helix and block cell replication (Lado & Yousef, 2002). This technique has been effectively used for disinfection of drinking water for many years. For other liquids, such as fruit juices, one of the most important limiting factors for the effectiveness of UVC treatment is lack of penetration as a result of solutes and particles in the juice (Wright, Sumner, Hackney, Pierson, & Zoeglein, 2000). In order to overcome this limitation, juices have to be mixed intensively in proximity to an energy source in order to target as many microorganisms as possible for inactivation. In this study, juice was subjected to UVC treatment in a device based on liquid flow in a helically arranged Teflon®-coil that caused secondary eddy flow effects (Dean effects) (Dean, 1927; Müller et al., 2011). More severe UVC effects on coliforms in watermelon juice might be due to their lower initial population and greater sensitivity to the inactivation treatment (Xu et al., 2011).

The microbe re-growth patterns in watermelon juice for all untreated and UVC treated samples at 2.7 and 37.5 J/mL during storage at 5 ± 1 °C for 37 days are presented in Fig. 2. Total aerobic bacteria in untreated samples increased up to the 14th day, reaching counts greater than 6.0 log CFU/mL (Fig. 2A), which has been called the upper acceptable microbial limit in fruit juices (Patrignani, Vannini, Kamdem, Lanciotti, & Guerzoni, 2009). Total aerobic bacteria in watermelon juice treated with 37.5 J/mL UVC showed a slower re-growth rate than juice treated at 2.7 J/mL. The population of coliforms (Fig. 2B) in untreated juice samples showed a decrease after 3 weeks of storage, while treated samples showed no significant ($P > 0.05$) changes throughout storage. Yeast/mold populations in untreated juice samples exceeded 6.0 log CFU/mL by the 14th day, and were almost 10 log CFU/mL after 37 days (Fig. 2C). Watermelon juice treated with 37.5 J/mL UVC showed a slower re-growth rate for yeast/mold than juice treated with a lower intensity (2.7 J/mL) UVC. Watermelon juice treated with 37.5 J/mL UVC had a shelf-life of approximately 31 days while stored at 5 ± 1 °C. Both the inactivation (Table 1) and re-growth (Fig. 2A, C) trends of aerobic bacteria

Table 1
Effects of different UVC intensities (J/mL) on microbial populations (log CFU/mL) in fresh watermelon juice.

UVC intensity (J/mL)	Microbial population (log CFU/mL)		
	Total aerobes	Coliform	Yeasts and mold
No treatment	2.73 ± 0.11^{d}	1.62 ± 0.20^{b}	3.47 ± 0.29^{c}
2.7	2.13 ± 0.01^{c}	ND^{a}	2.94 ± 0.04^{b}
5.4	2.16 ± 0.08^{c}	ND^{a}	2.87 ± 0.05^{ab}
9.4	1.46 ± 0.07^{b}	ND^{a}	2.47 ± 0.07^{a}
37.5	1.26 ± 0.14^{a}	ND^{a}	2.48 ± 0.03^{a}

ND = not determined (levels of microbial populations studied were below 1.0 log CFU/mL).
Values are expressed as mean ± standard deviation ($n = 3$).
Different lower-case superscript letters in the same column show significant differences ($P < 0.05$).

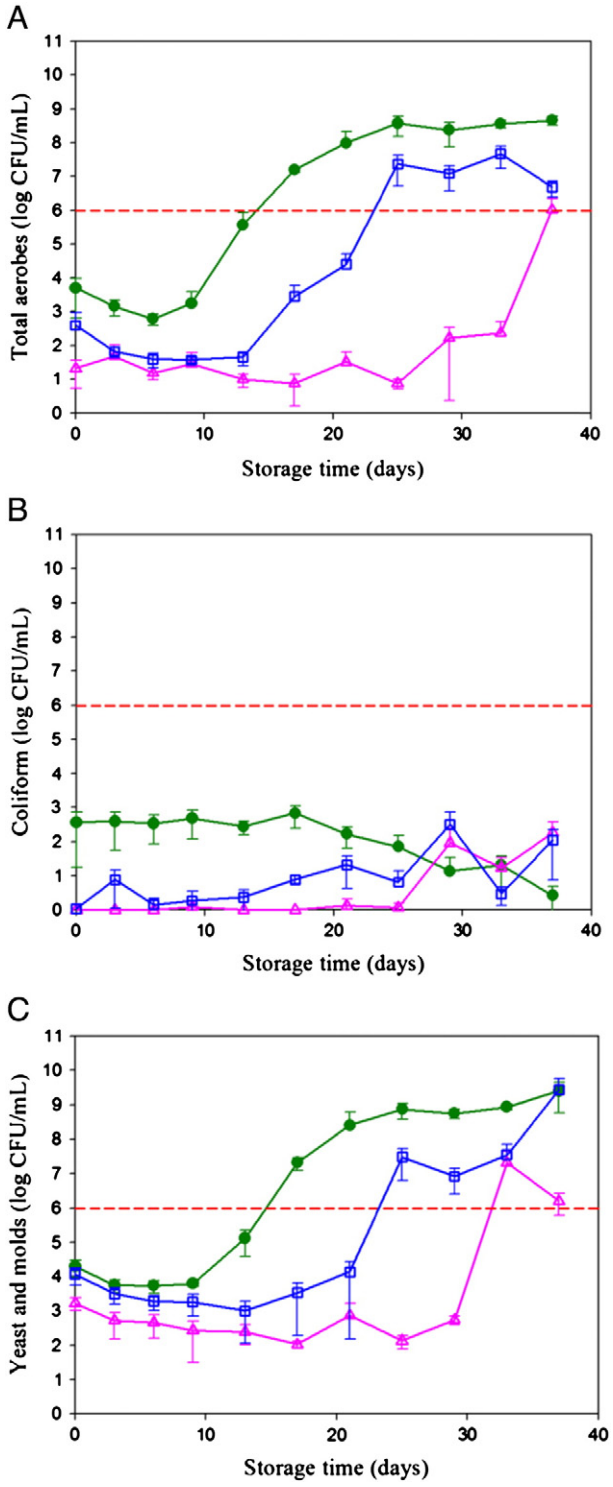

Fig. 2. Changes in total aerobic bacteria (A), coliform bacteria (B), and yeast/mold (C) counts in untreated and UVC treated watermelon juice during storage at 5 ± 1 °C. Error bars represent the standard deviations ($n = 3$). No treatment (●), 2.7 J/mL UVC (□), 37.5 J/mL UVC dosage (△). The dotted line shows the upper acceptable limit of 6.0 log CFU/mL.

and yeast/mold were similar and in agreement with growth of aerobic bacteria and yeasts during storage of high pressure treated cabbage (Li et al., 2010). Other reports have also shown benefits of UVC treatment for extending the microbiological shelf-life of fruits and their products, such as strawberries (Pombo, Dotto, Martínez, & Civello, 2009), fresh-cut apple (Manzocco, Dri, & Quarta, 2009), fresh-cut watermelon (Artés-Hernández, Robles, Gómez, Tomás-Callejas, & Artés, 2010), apple juice (Franz et al., 2009), and orange juice (Tran & Farid, 2004). UVC treatment of watermelon juice in a Teflon®-coil based system was effective for significantly reducing microbial counts and increasing the shelf-life of juice during refrigerated storage.

3.2. Effects of UVC on pH and the °brix values of juice

Values for pH and °brix of untreated watermelon juice and juice treated with UVC (2.7 J/mL and 37.5 J/mL) during 37 days storage at 5 ± 1 °C are shown in Table 2. The pH of all three treatments remained similar up to 25 days, after which UVC treated samples had significantly higher pH values. A marked decrease in pH (from 5.34 to 5.13) for untreated juice was observed with an increasing storage period from 0 to 37 days. Both types of UVC treatment resulted in significant increases in pH (from 5.35 to 6.20 and from 5.34 to 6.05) with storage time, consistent with results for re-growth patterns of microorganisms in juice during storage. Furthermore, in UVC treated juice, microbes were unable to increase the acid production at a rate similar to the rate before UVC treatment. This resulted in an overall increase in the pH of treated juice, whereas the untreated juice exhibited a pH decrease due to faster growth of aerobic bacteria and yeast/mold. Nualkaekul and Charalampopoulos (2011) observed that pH values in orange, grapefruit, blackcurrant, pomegranate, cranberry, and lemon juice decreased, while the lactic acid and acetic acid amounts increased with storage time, suggesting more microorganisms metabolizing available energy sources. °Brix values remained similar for all treatments up to 25 days, after which treated samples had significantly higher values. Storage time did not show significant effects on the °brix values of all watermelon juice samples.

3.3. Effects of UVC on the lycopene and phenolic contents of juice

Results for total lycopene and phenolic contents, in UVC treated and untreated watermelon juice, are shown in Table 3. Total lycopene in all types of watermelon juice was in the range of 35–37 mg/L on day 0, which is comparable to previously reported results (Oms-Oliu et al., 2009). Differences in total lycopene for all three treatments remained (mostly) insignificant up to 25 days of storage. Further storage showed significantly higher values of total lycopene in untreated juices. It has been reported that the lycopene content can increase during storage, e.g. in tomatoes, depending on post-harvest treatments and storage conditions (Javanmardi & Kubota, 2006). The UVC intensity had little or no effect on the lycopene content of watermelon juice. The exact effect of UV radiation, whether to increase or decrease the amount of lycopene, has not been explained with clarity. Chen et al. (2009) suggested that either an increase in exposure to radiation or increment in radiation intensity resulted in degradation and isomerization of lycopene. They also proposed that a greater percentage of lycopene loss, as compared to gain, in the *cis*-isomer form suggested that oxidation of lycopene was the main mechanism for lycopene loss. However, it has been also reported that radiation treatment enhances the total lycopene content in tomatoes (Liu, Zabaras, Bennett, Aguas, & Woonton, 2009) and that long term UVC treatment and exposure to radiation during storage can cause photo degradation of natural pigments (Bąkowska, Kucharska, & Oszmiański, 2003). Photons of UV radiation at 253.7 nm are absorbed by organic molecules and affect conjugated bonds, such as aromatic rings, double rings, and compounds containing disulfide bonds (Koutchma, 2009). In this study, Teflon®-coil reactor with UVC radiation at 254 nm was used with varying UVC exposure time to ensure the application of certain UVC intensity. Results show no significant ($P > 0.05$) change in the total lycopene content which exhibit good stability during 25 days of storage. Even higher intensity UVC exposure (37.5 J/mL) had no significant effect on the lycopene content. Values of treated samples remained similar to the control.

Total phenolic compounds in untreated fresh watermelon juice were 19.22 mg GAE/mL (Table 3). Phenolic compounds are secondary

Table 2
pH and °brix values of UVC treated and untreated watermelon juice during 37 days of storage at 5 ± 1 °C.

Storage time (days)	pH			°Brix		
	No treatment	2.7 J/mL UVC	37.5 J/mL UVC	No treatment	2.7 J/mL UVC	37.5 J/mL UVC
0	5.34 ± 0.14^{aAB}	5.35 ± 0.15^{aA}	5.34 ± 0.15^{aA}	9.47 ± 0.72^{aA}	9.46 ± 0.71^{aA}	9.45 ± 0.74^{aA}
3	5.41 ± 0.14^{aABC}	5.43 ± 0.13^{aAB}	5.43 ± 0.12^{aAB}	9.52 ± 0.69^{aA}	9.52 ± 0.73^{aA}	9.54 ± 0.68^{aA}
6	5.44 ± 0.16^{aABC}	5.49 ± 0.11^{aAB}	5.47 ± 0.12^{aAB}	9.63 ± 0.65^{aA}	9.60 ± 0.68^{aA}	9.60 ± 0.68^{aA}
9	5.47 ± 0.11^{aBC}	5.48 ± 0.11^{aAB}	5.47 ± 0.13^{aAB}	9.69 ± 0.64^{aA}	9.69 ± 0.64^{aA}	9.66 ± 0.65^{aA}
13	5.47 ± 0.14^{aBC}	5.50 ± 0.11^{aAB}	5.49 ± 0.11^{aAB}	9.74 ± 0.62^{aA}	9.72 ± 0.63^{aA}	9.71 ± 0.64^{aA}
17	5.68 ± 0.06^{aCD}	5.69 ± 0.04^{aB}	5.67 ± 0.02^{aB}	10.04 ± 0.18^{aA}	10.12 ± 0.13^{aA}	10.06 ± 0.16^{aA}
21	5.63 ± 0.08^{bBCD}	5.48 ± 0.12^{aAB}	5.49 ± 0.13^{aAB}	9.47 ± 0.55^{aA}	9.62 ± 0.61^{aA}	9.54 ± 0.69^{aA}
25	5.89 ± 0.04^{bD}	5.62 ± 0.05^{aAB}	5.63 ± 0.08^{aB}	9.21 ± 0.66^{aA}	9.80 ± 0.56^{aA}	9.80 ± 0.55^{aA}
29	5.30 ± 0.14^{aAB}	5.64 ± 0.15^{bAB}	5.53 ± 0.12^{bAB}	9.85 ± 0.01^{aA}	10.12 ± 0.13^{bA}	10.12 ± 0.12^{bA}
33	5.30 ± 0.35^{aAB}	6.03 ± 0.52^{bC}	5.60 ± 0.02^{abAB}	9.45 ± 0.20^{aA}	10.13 ± 0.13^{bA}	10.13 ± 0.12^{bA}
37	5.13 ± 0.62^{aA}	6.20 ± 0.29^{bC}	6.05 ± 0.51^{bC}	9.40 ± 0.21^{aA}	10.14 ± 0.13^{bA}	10.13 ± 0.11^{bA}

Values are expressed as mean ± standard deviation ($n = 3$).
Different lower-case superscript letters in the same row for each day indicate significant differences among treatments ($P < 0.05$).
Different capital superscript letters in the same column for each treatment correspond to significant differences with time ($P < 0.05$).

metabolites in plants that are known to be important for imparting health benefits and for developing the color and flavor of fruit juices and wine. Phenolics degrade, oxidize, or polymerize quickly during processing and storage. Therefore, total phenolic content is an important indicator of the quality of fruit juice (Ghafoor & Choi, 2012). As shown in Table 3, different UVC intensities had no significant ($P > 0.05$) effect on phenolic compounds, in comparison to untreated juice samples. Different reports concerning the effects of the UV dosage on the phenolic content of fruit juices are available. Noci et al. (2008) applied UVC to fresh apple juice and reported a significant decrease in total phenolic compounds, compared to fresh juice. Caminiti et al. (2012) exposed apple juice to UVC radiation (2.66–53.10 J/cm^2) using a rising film UVC reactor and found that there were no significant changes in total phenolic compounds. In addition, Pala and Toklucu (2011) reported that UVC treatment did not affect phenolic compounds in pomegranate juice. A well-designed reactor that allows sufficient exposure of liquids to UVC in a shorter time can be used to obtain microbiologically safe juices with minimal or no damage to bioactive components.

3.4. Effects of UVC on the color (L*, a*, b*, and ΔE) of juice

The results of UVC treatment on color parameters in treated and untreated watermelon juice during 37 days storage at 5 ± 1 °C are presented in Table 4. The L* value (lightness) of both treated and untreated juice remained similar up to 2 days, after which untreated juice had a higher L* value. This increase in the darkness value can be attributed to partial precipitation of unstable suspended particles. The yellowness, or b* value, of treated juices, especially at 37.5 J/mL, was significantly ($P < 0.05$) lower than for untreated juices. The value of a*, which reflects the redness (the main color of watermelon juice), remained mostly similar for treated and untreated juice. UVC treatment had a positive effect on a* value. It was previously reported that UVC treatment did not influence the redness of pepper (Vicente et al., 2005); however, we observed variations from this result of watermelon juice, perhaps due to the different textures and microstructures of watermelon juice and pepper that cause changes in the nature and extent of internally scattered light and the distribution of surface reflectance (Oey, Lille, Loey, & Hendrickx, 2008). The a*/b* ratio of fruit colors can be used as a reference parameter for red color development (Arias, Lee, Logendra, & Janes, 2000). A higher a* value and a lower b* value will result in a redder color. Similar values were obtained for all treated juice samples. Despite an increase in the amount of lycopene during storage after 25 days of storage, the red color did not improve to a similar extent in untreated juice. Instead, this increase was reflected in higher L* values for untreated juice after 25 days. Javanmardi and Kubota (2006) also noted that despite an increase in lycopene contents in tomato during storage, the antioxidant activity and total soluble solids did not increase. Therefore, it appears that the cloudiness increased in untreated watermelon juice. The total color change (ΔE) of treated juice samples was not significant as the value remained mostly lower than 3.0, whereas untreated juice showed a significant ΔE after 21 days with values higher than 3.0 (Varela-Santos et al., 2012). Storage time had an important ($P < 0.05$) effect on the L*, a*, and b* values of both treated and untreated juice samples. L* values increased, while a* and b* values decreased with increasing storage time at 5 ± 1 °C.

Table 3
Changes in the lycopene content and the total phenolic compounds of UVC treated and untreated watermelon juice during 37 days of storage at 5 ± 1 °C.

Storage time (days)	Lycopene contents (mg/L)			Total phenolic compounds (mg GAE/mL)		
	No treatment	2.7 J/mL UVC	37.5 J/mL UVC	No treatment	2.7 J/mL UVC	37.5 J/mL UVC
0	36.76 ± 2.56^{aB}	35.43 ± 3.01^{aBC}	35.37 ± 2.24^{aD}	16.94 ± 1.58^{aAB}	16.47 ± 2.04^{aABC}	16.96 ± 2.14^{aA}
3	37.71 ± 2.87^{aB}	38.59 ± 3.32^{aCD}	36.07 ± 2.79^{aD}	19.57 ± 2.85^{aBCD}	18.39 ± 1.94^{aABC}	18.36 ± 2.13^{aAB}
6	35.23 ± 2.53^{aB}	34.81 ± 3.63^{aBC}	34.23 ± 2.66^{aCD}	17.51 ± 3.27^{aABC}	17.22 ± 3.52^{aABC}	17.15 ± 3.10^{aA}
9	27.95 ± 2.92^{aA}	28.83 ± 2.45^{aA}	28.53 ± 2.70^{aA}	17.46 ± 1.26^{aABC}	16.94 ± 1.23^{aABC}	17.40 ± 1.13^{aA}
13	34.95 ± 3.15^{aB}	33.47 ± 2.80^{aB}	32.71 ± 2.34^{aBCD}	16.04 ± 2.08^{aA}	16.15 ± 0.96^{aAB}	16.08 ± 1.31^{aA}
17	37.73 ± 1.26^{abB}	39.28 ± 3.50^{bD}	34.42 ± 3.28^{aCD}	17.74 ± 2.70^{aABC}	15.50 ± 2.12^{aA}	16.63 ± 2.96^{aA}
21	34.12 ± 3.26^{bB}	33.12 ± 2.41^{abB}	31.00 ± 1.40^{aABC}	15.73 ± 1.49^{aA}	15.33 ± 1.49^{aA}	16.22 ± 2.03^{aA}
25	36.80 ± 1.80^{aB}	35.41 ± 0.21^{aBC}	33.94 ± 4.19^{aCD}	16.43 ± 2.12^{aAB}	16.57 ± 1.58^{aABC}	16.94 ± 1.29^{aA}
29	44.81 ± 4.68^{bC}	31.79 ± 2.29^{aB}	29.42 ± 2.81^{aAB}	15.66 ± 1.71^{aA}	15.23 ± 2.06^{aA}	15.32 ± 1.40^{aA}
33	50.75 ± 4.05^{bD}	33.21 ± 1.17^{aB}	34.25 ± 1.17^{aCD}	20.78 ± 2.21^{aD}	19.35 ± 2.07^{aC}	19.01 ± 2.55^{aAB}
37	43.21 ± 2.12^{bC}	34.82 ± 0.70^{aBC}	35.09 ± 2.47^{aCD}	20.23 ± 1.38^{aCD}	18.74 ± 3.19^{aBC}	20.74 ± 6.53^{aB}

Values are expressed as mean ± standard deviation ($n = 3$).
Different lower-case superscript letters in the same row for each day indicate significant differences among treatments ($P < 0.05$).
Different capital superscript letters in the same column for each treatment correspond to significant differences with time ($P < 0.05$).

Table 4
Color (L^*, a^*, b^*) values and total color change of UVC treated and untreated watermelon juice during 37 days of storage at 5 ± 1 °C.

Storage time (days)	L^*			a^*			b^*			Total color change (ΔE)		
	No treatment	2.7	37.5	No treatment	2.7	37.5	No treatment	2.7	37.5	No treatment	2.7	37.5
		J/mL	J/mL		J/mL	J/mL		J/mL	J/mL		J/mL	J/mL
0	21.52 ± 0.50^{aA}	21.31 ± 0.38^{aA}	21.64 ± 0.27^{aAB}	7.72 ± 0.52^{aC}	7.64 ± 0.56^{aB}	7.91 ± 0.58^{aC}	8.13 ± 0.31^{cCD}	7.91 ± 0.12^{bABC}	7.27 ± 0.09^{aC}	0.00	0.31	0.90
3	21.45 ± 0.60^{aA}	21.43 ± 0.40^{aA}	21.38 ± 0.42^{aA}	7.36 ± 0.69^{aC}	7.44 ± 0.50^{aAB}	7.83 ± 0.45^{aC}	7.98 ± 0.61^{bBCD}	7.84 ± 0.45^{bABC}	7.23 ± 0.35^{aC}	0.40	0.42	0.92
6	21.31 ± 1.15^{aA}	20.92 ± 0.58^{aA}	21.39 ± 0.65^{aA}	7.20 ± 0.59^{aC}	7.38 ± 0.69^{aAB}	7.80 ± 0.72^{aC}	8.16 ± 0.24^{bCD}	8.34 ± 0.41^{bC}	7.37 ± 0.10^{aCD}	0.56	0.72	0.78
9	21.44 ± 0.76^{aA}	21.05 ± 0.57^{aA}	21.42 ± 0.66^{aA}	7.22 ± 0.39^{aC}	7.35 ± 0.50^{aAB}	7.80 ± 0.43^{bC}	8.36 ± 0.26^{bD}	8.17 ± 0.22^{bBC}	7.71 ± 0.45^{aD}	0.55	0.60	0.44
13	21.22 ± 0.61^{aA}	21.21 ± 0.79^{aA}	22.29 ± 1.25^{aABC}	6.96 ± 0.85^{aBC}	7.34 ± 0.51^{aAB}	7.25 ± 0.31^{aBC}	6.66 ± 0.84^{bA}	7.02 ± 0.48^{bA}	5.83 ± 0.31^{aB}	1.68	1.22	2.47
17	21.83 ± 0.26^{aA}	22.22 ± 0.67^{aAB}	21.71 ± 0.18^{aAB}	7.05 ± 0.95^{aBC}	6.97 ± 0.14^{aAB}	7.55 ± 0.33^{aBC}	7.00 ± 0.24^{bABC}	6.92 ± 0.39^{bA}	5.29 ± 0.26^{aA}	1.35	1.59	2.85
21	24.21 ± 4.10^{aAB}	23.98 ± 1.67^{aC}	23.23 ± 0.66^{aCD}	6.54 ± 0.89^{aABC}	7.31 ± 0.43^{bAB}	6.99 ± 0.48^{abB}	6.63 ± 0.63^{bA}	6.92 ± 1.05^{bA}	5.12 ± 0.51^{aA}	3.30	2.77	3.54
25	25.41 ± 2.45^{bABC}	22.94 ± 1.22^{aB}	22.47 ± 0.24^{aABC}	6.59 ± 0.61^{aABC}	6.91 ± 0.76^{aAB}	7.31 ± 0.53^{aBC}	8.21 ± 0.94^{cCD}	7.21 ± 0.68^{bAB}	5.73 ± 0.35^{aB}	4.05	1.88	2.62
29	29.29 ± 6.85^{bD}	20.96 ± 0.85^{aA}	23.70 ± 1.20^{aD}	5.80 ± 1.51^{aAB}	6.52 ± 0.70^{aA}	6.29 ± 0.68^{aA}	7.44 ± 2.07^{bABCD}	7.31 ± 0.99^{bAB}	5.15 ± 0.26^{aA}	8.04	1.56	3.96
33	27.36 ± 1.80^{bBCD}	21.66 ± 0.39^{aA}	22.61 ± 0.19^{aBC}	5.60 ± 1.20^{aA}	7.01 ± 0.34^{bAB}	6.93 ± 0.41^{bB}	6.83 ± 0.38^{aAB}	7.24 ± 1.37^{aAB}	5.97 ± 0.51^{aB}	6.35	1.15	2.55
37	28.18 ± 0.70^{bCD}	21.62 ± 0.30^{aA}	21.97 ± 0.37^{aAB}	6.49 ± 1.09^{aABC}	6.70 ± 0.73^{aA}	7.25 ± 0.29^{aBC}	7.78 ± 0.17^{bABCD}	7.95 ± 0.07^{cABC}	6.02 ± 0.10^{aB}	6.78	1.04	2.21

Valuesare expressed as mean ± standard deviation ($n = 3$).
Different lower-case superscript letters in the same row for each day indicate significant differences among treatments ($P < 0.05$).
Different capital superscript letters in the same column for each treatment correspond to significant differences with time ($P < 0.05$).

4. Conclusions

UVC radiation can be effectively applied as a non-thermal method for assuring microbial safety that maintains the physico-chemical qualities of watermelon juice. Application of UVC (2.7–37.5 J/mL) completely inactivated the coliform bacterial population. A 37.5 J/mL UVC treatment resulted in 50% and 30% reductions in total aerobic bacteria and yeast and mold, respectively. During storage at 5 ± 1 °C, total aerobes, coliforms, and yeast/mold remained lower than 6.0 log CFU/mL in UVC treated juice samples for 31 days. Differences in the values for pH, °brix, total lycopene, and total phenolic compounds for treated juice and control samples were insignificant, suggesting good stability of watermelon bioactive compounds for approximately 25 days after UVC treatment. Total color change, yellowness, and lightness/darkness of treated watermelon juice remained lower than control values, whereas redness and the a*/b* ratio were higher. Similarly, the color change in treated juice was not significantly different from control values, suggesting that UVC treatment has positive effects on the color quality of juice during storage. Application of UVC in a Teflon®-coil reactor resulted in longer shelf-stability and better quality watermelon juice. Hence, this process can be effectively applied as a non-thermal method to ensure microbial safety while maintaining the physico-chemical qualities of this juice product.

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