Journal of Food Processing and Preservation ISSN 1745-4549

EFFECTS OF UV-C IN A TEFLON-COIL AND HIGH HYDROSTATIC PRESSURE COMBINED TREATMENT FOR MAINTENANCE OF THE CHARACTERISTIC QUALITY OF DONGCHIMI (WATERY RADISH KIMCHI) DURING ROOM TEMPERATURE STORAGE

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Received for Publication December 3, 2015
Accepted for Publication March 28, 2016

doi:10.1111/jfpp.13057

ABSTRACT

The effect of nonthermal ultraviolet-C light in a Teflon-coil (UV-C, fixed at 2.5 J/mL) and subsequent high hydrostatic pressure (HHP at 400–500 MPa at 25C for 1 min) combined treatment was evaluated in dongchimi juice during 5-day storage at room temperature. A helically wound Teflon-coil reactor was used for UV-C radiation to create a secondary eddy flow. Results showed that lactic acid bacteria (LAB) in dongchimi juice were more resistant to UV-C and HHP alone treatments. On the other hand, UV-HHP combined treatment resulted in greater reduction of LAB viable counts and also inhibited bacterial growth during room temperature storage and maintained the chemical quality of dongchimi juice via synergistic effect. Sensory analysis showed that nonthermal treatments effectively maintained the taste and flavor of dongchimi juice during room temperature storage than untreated and heat pasteurized samples. In conclusion, UV-HHP combined treatment offers an opportunity for marketing of dongchimi juice product at room temperature with characteristic quality.

PRACTICAL APPLICATIONS

Over-ripening of dongchimi (Korean watery radish kimchi) resulting from spontaneous LAB fermentation leads to development of an undesirable taste in the final product, and restricts marketing. This study attempted to overcome the issues of over-ripening in dongchimi juice by controlling LAB fermentation during storage using a combined application of nonthermal treatments such as UV-C light in a Teflon-coil and HHP via synergistic effect, without affecting characteristics of quality and freshness of this product. Available data from this study will benefit the food processing industry to introduce dongchimi juice product of characteristic quality with an extended palatable shelf life at room temperature.

INTRODUCTION

Fermented vegetables are popular around the globe. Examples include sauerkraut from Europe and kimchi from Korea (Sohn and Lee 1998; Panda *et al.* 2007; Li *et al.* 2010; Peñas *et al.* 2010; Rhee *et al.* 2011; Cagno and Coda 2014). Kimchi is one of the main ethnic dishes that have gained global popularity among consumers who like sour, tangy and bitter fermented flavors. The kimchi flavor has been placed among the top five trendy flavors (Hensel 2014). Fermentation of kimchi is carried out using LAB and the process is controlled by used temperature, salt concentration, ingredients, fermentation period and microbial species (Park *et al.* 2010; Rhee *et al.* 2011). Dongchimi is typically a watery kimchi prepared from ripened radish as a main ingredient with a mix of seasonings (Lee e*t al.* 2012; Jeong *et al.* 2013). Dongchimi juice (liquid soup), the end product, has a unique

carbonic, sour and tangy taste due to LAB fermentation. Dongchimi juice is served with noodles and Korean barbeque and also used as a base for many Korean dishes (Cho *et al.* 2015). The probiotic effect of LAB in dongchimi juice contributes to digestive and intestinal functions for human health (Lee *et al.* 2010; Rhee *et al.* 2011).

The most serious issue with dongchimi quality is continuous acid production by spontaneous LAB fermentation after an optimum ripening stage that often leads to development of an undesirable taste and odor in the final product. These undesirable changes which diminish product quality are called “over-ripening” of dongchimi. Therefore, dongchimi juice needs to be refrigerated to avoid rapid deterioration of its characteristic quality (Lee *et al.* 2010; Rhee *et al.* 2011). The use of low-temperature storage, heat sterilization, irradiation and addition of salt or natural preservatives, such as chitosan, for LAB growth inhibition in dongchimi to control over-ripening was reported previously by a number of research studies (Lee *et al.* 2010). In addition, there have been several attempts to develop a beverage product using dongchimi juice but no product has been commercialized (Cho *et al.* 2015).

Modern consumers are interested in high quality food products with a fresh flavor (Koutchma 2009; Gabriel *et al.* 2015; Juarez-Enriquez *et al.* 2015). Hence, it is important to control LAB growth for prevention of over-ripening without affecting the characteristic quality of dongchimi juice. The general limitations of thermal pasteurization include an undesirable product quality and organoleptic changes in foods (Juarez-Enriquez *et al.* 2015; Andrés *et al.* 2016). There is a growing interest in nonthermal technologies that can contribute to food safety without affecting product quality and freshness (Houska *et al.* 2006; Considine *et al.* 2008; Gabriel *et al.* 2015). UV light is currently replacing many traditional pasteurization procedures for liquid foods due to its multiple advantages (Feng *et al.* 2013; Gabriel *et al.* 2015; Liu *et al.* 2015). However, UV light has very shallow penetration in liquid foods due to the presence of large amount of absorbing compounds and suspended particles, thereby limiting its industrial applications in food processing (Koutchma 2009; Nogales-Delgado *et al.* 2014; Liu *et al.* 2015). Therefore, an effective strategy for increasing the microbial inactivation efficiency during food processing is the use of combined treatments to produce a synergistic inactivation effect (Noci *et al.* 2008; Chai *et al.* 2014; Palgan *et al.* 2011; Shahbaz *et al.* 2016a). HHP is another promising nonthermal technology due to a high degree of microbiological safety and stability with minimal effects on product quality and freshness and, thereby increasing the product shelf life (Manas and Pagan 2005; Considine *et al.* 2008; Bermúdez-Aguirre and Barbosa-Cánovas 2011; Hiremath and Ramaswamy 2012). The combined application of HHP with UVC/TiO_2 has been reported for achieving synergistic inactivation of microorganisms in apple juice (Shahbaz *et al.* 2016a), orange juice (Yoo *et al.* 2015) and *Angelica keiskei* juice (Chai *et al.* 2014). Sohn and Lee (1998) suggested the need to use HHP in combination with other technologies for minimization of browning effects to extend the shelf life of commercially produced kimchi products.

The objective of this study was to evaluate the effect of UV-C light (Teflon-coil reactor) and HHP combined treatment to overcome the problem of over-ripening in dongchimi watery kimchi based on control of spontaneous LAB fermentation. Extension of the palatable life of the product with a characteristic quality at room temperature storage is desirable, along with creation of marketing opportunities.

MATERIALS AND METHODS

Preparation of Dongchimi

Dongchimi samples were prepared according to a traditional procedure shown in Fig. 1 (Lee *et al.* 2012; Jeong *et al.* 2013). The main raw ingredients included white radish (*Raphanus sativus* L.), garlic (*Allium sativum*), green onion (*Allium cepa*), ginger (*Zingiber officinale*) and solar salt (CJ Co., Seoul, South Korea), which were all purchased from a local supermarket (Agricultural Cooperative Marketing, Inc., Seoul, South Korea). Briefly, radish and other ingredients were rinsed and chopped, followed by mixing with a brine solution of 2.5% sodium chloride in distilled water. The vegetable mixture was left for fermentation until a pH value between pH 4.15–4.25 was attained for production of an optimal taste. Dongchimi juice was periodically sampled during fermentation for pH testing. A tangy flavored refreshing dongchimi juice (liquid soup) produced as a result of fermentation was used for further processing and analysis.

Processing Treatments

Nonthermal Processing Treatments (Alone and Combined) of Dongchimi Juice. *UV-C Radiation in a Teflon-Coil Reactor*. The UV-C reactor used here was previously described by Feng *et al.* (2013). UV-C reactor was consisted of a helically wound polytetrafluoroethylene Teflon tube with an internal volume of 160 mL wrapped around a quartz glass tube and equipped with a UV-C lamp (254 nm; 75 W output; Sankyo Denki Co., Ltd., Hiratsuka, Japan). The helical configuration of the Teflon-coil around the UV-C bulb ensured that the entire liquid sample passed through the UV-C zone for effective disinfection. A cooling water circulation system was used for temperature control and to avoid heating of liquid samples. The liquid flow rate was maintained at 30 mL/s using a peristaltic pump. The temperature was kept at 10C for all experiments. The UV-C

FIG. 1. PROCESSING SCHEME FOR PREPARATION OF DONGCHIMI (KOREAN WATERY RADISH KIMCHI)

dosage, fixed at 2.5 J/mL, was determined based on the energy delivered per volume of liquid and was expressed as J/mL. The UV dosage through the reactor was theoretically calculated using Eq. (1) (Keyser *et al.* 2008):

$$\text{UV-C dosage}\left(\frac{\text{J}}{\text{mL}}\right)=\frac{\text{Total UV-C output power (W)}}{\text{Flow rate}\left(\frac{\text{mL}}{\text{s}}\right)}. \quad (1)$$

High Hydrostatic Pressure. A pilot scale HHP unit was used for dongchimi juice treatment (HPP-600, Baotou Kefa, Co., Ltd., Inner Mongolia, China). This 5 L capacity unit could apply pressure of up to 600 MPa. Distilled water was used as a high-pressure transmission fluid working at a ramp rate of 17 MPa/s while the decompression time was 5–8 s. Dongchimi juice samples (untreated, and UV-C treated) were sealed in flexible PET pouches (10 × 15 cm) and heat-sealed leaving no head space. Packed samples were loaded into the vessel and pressurized at 400–500 MPa for 1 min holding time at 25C. Experimental conditions were controlled using a PC-driven acquisition and control system. After treatment, samples were immediately placed in a low-temperature incubator for cooling. Three different batches ($n = 3$) were treated and results were independently subjected to statistical analysis.

Heat Treatment. For comparison of quality changes associated with nonthermal processing, heat treatment was carried out in a water bath equipped with an electrical heater (KSB-201, Sunileyela, Seongnam, South Korea). Briefly, each 500 mL of dongchimi juice sample was placed in a glass beaker, covered with aluminum foil and immersed in the water bath at 80C. Samples were heated for 2 min when the internal product temperature was reached at 80C. Care was taken to ensure that the whole content of samples was completely submerged in the water during the heat treatment. Samples were cooled before packaging.

Storage of the Processed Dongchimi Juice. Treated and untreated control dongchimi juice samples were sealed in PET bags (10 × 15 cm) using a sealer (Pack Town Co., Daegu, South Korea). All samples were stored at 25C for a 5 days storage study.

Analysis of Processed Dongchimi Juice

Lactic Acid Bacterial (LAB) Counts. Stomached samples were analyzed for LAB counts using the pour plate method on MRS agar (Difco, Franklin Lakes, NJ). LAB were incubated at 30C for 48 h before colonies were counted. Changes in LAB counts were determined every 12 h during the storage period. Results were reported as CFU/mL.

Chemical Analysis

pH and Titratable Acidity. For measurement of pH, dongchimi juice was first centrifuged at 6,000 × g for 1 min. The pH value of approximately 10 mL of a liquid sample was recorded using a pH meter at ambient temperature (Orion 520A, Orion Research, Inc., Boston, MA). The titratable acidity level of liquid was measured following a standard AOAC protocol and was expressed as % lactic acid. Readings were taken three times and mean values were reported.

Organic Acids. The concentration of organic acids were measured using HPLC system (Dionex Corp., Sunnyvale, CA) according to Andrés *et al.* (2016) with slight modifications. An analytical column Capcell Pak C18 MG (4.6 mm × 250 mm; Shiseido Co., Ltd., Tokyo, Japan) was used. Liquid sample of 5.0 mL were added to 20 mL of a 4.5% metaphosphoric solution. The mixture was homogenized and centrifuged at 1,640 × g for 15 min (MF550, Hanil, Incheon, South Korea). For measurement of lactic acid, malic acid and acetic acid, an aliquot of the supernatant (20 μL) was passed through the Millipore membrane (0.45 μm membrane filter, Millipore, Bedford, MA) and injected into the HPLC system. The mobile phase was 0.005 M sulfuric acid, and flow rate was 0.5 mL/min. The HPLC system was working at 210 nm and 62C. For the measurement of ascorbic acid, the mobile phase consisted of water and methanol in a ratio 95:5 (v/v). The flow rate was maintained at 1.0 mL/min. The HPLC system was working at 254 nm. All measurements were carried out in triplicate.

Sensory Analysis

An untrained panel of 30 members comprising both male and female panelists of 20–30 years of age voluntarily collaborated for sensory analysis. Only members were selected who consumed dongchimi juice at least once a week. Panelists were given appropriate information about the research project and intended objectives. Required definitions for sensory parameters were explained prior to evaluation. Approximately 10 mL of dongchimi juice (treated or untreated control at 25C) was presented to panelists in a white plastic cup coded with a three-digit random number at a 5 min interval frequency. Panelists were provided deionized water and unsalted crackers for palate rinsing during the interval. Quality parameters of dongchimi juice in terms of flavor, taste, color and overall preference were rated on a 5-point scale from “like extremely = 5” to “dislike extremely = 1.”

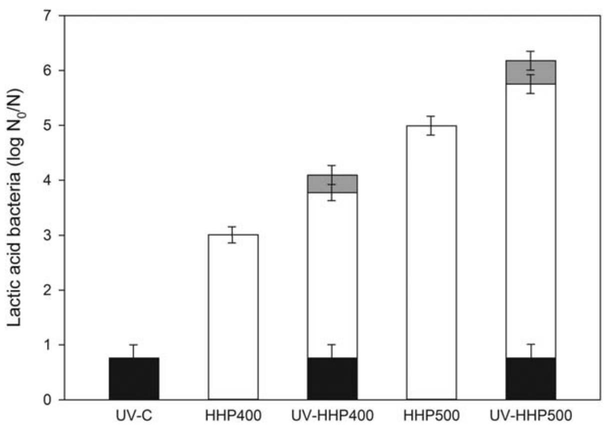

FIG. 2. EFFECTS OF A TEFLON-COIL UV-C, HHP AND COMBINED UV-HHP TREATMENTS FOR INACTIVATION OF LAB IN DONGCHIMI JUICE

Black bars represent the UV-C alone effect, white bars represent the HHP alone effect, and gray bars represent the synergistic effect (UV-HHP). $n_0 = 7.98$ log cfu/mL. Error bars represent mean ± standard deviation ($n = 3$).

Statistical Analysis

A one-way ANOVA and multiple comparisons were carried out using the Statistical Package for Social Sciences (SPSS, version 18, IBM Corp., Armonk, NY). ANOVA testing was performed for all experimental runs for determination of the significance at a 95% confidence level. All experiments were performed in triplicate. Results were considered significant at $P < 0.05$.

RESULTS AND DISCUSSION

Inactivation of Lactic Acid Bacteria (LAB)

The mean initial LAB cell number in control samples was 7.98 log CFU/mL. UV-C alone treated samples exhibited reductions of 0.76 log CFU/mL in LAB counts, while LAB counts for HHP alone treated samples at 400 and 500 MPa were reduced to 3.01 and 4.99 log CFU/mL, respectively (Fig. 2). On the other hand, UV-HHP combined treatment at 400 and 500 MPa caused greater reduction in LAB counts via a synergistic effect with values of 4.09 and 6.18 log CFU/mL, respectively (Fig. 2). LAB populations were counted in samples during 5-day storage at 25C at 12 h interval (Fig. 3). UV-HHP combined treatment at pressure level of 500 MPa effectively inhibited the growth of LAB for a longer period during storage compared with HHP alone treated, heat treated and untreated samples (Fig. 3B). Heat treatment resulted in reduction of 4.90 log CFU/mL to the initial LAB counts (data not shown), but did not prove effective to control microbial growth during storage (Fig. 3). Therefore, the use of nonthermal UV-HHP combined treatment was more effective for inhibition of LAB fermentation and for prevention of dongchimi over-ripening during storage.

Fermented vegetables are generally considered safe due to the presence of LAB (Peñas *et al.* 2010; Cagno and Coda 2014). Kimchi is one of the most popular fermented foods in Korea with hundreds of varieties that make a significant contribution to the Korean diet (Park *et al.* 2010; Rhee *et al.* 2011). Sohn and Lee (1998) reported that low-pressure treatments of 200 MPa partially damaged LAB and other heterofermentors in kimchi. Numbers of LAB were further reduced to 10^3 CFU/mL after pressure treatments at 600 MPa for 10 min at 25C. Teflon-coil UV treatment at 37.5 J/mL caused reductions of 1.47 and 0.99 log CFU/mL in total aerobes and yeast/molds, respectively, in watermelon juice (Feng *et al.* 2013). UV-C light at 200–280 nm has exhibited germicidal effects against bacteria, yeast/molds and viruses.

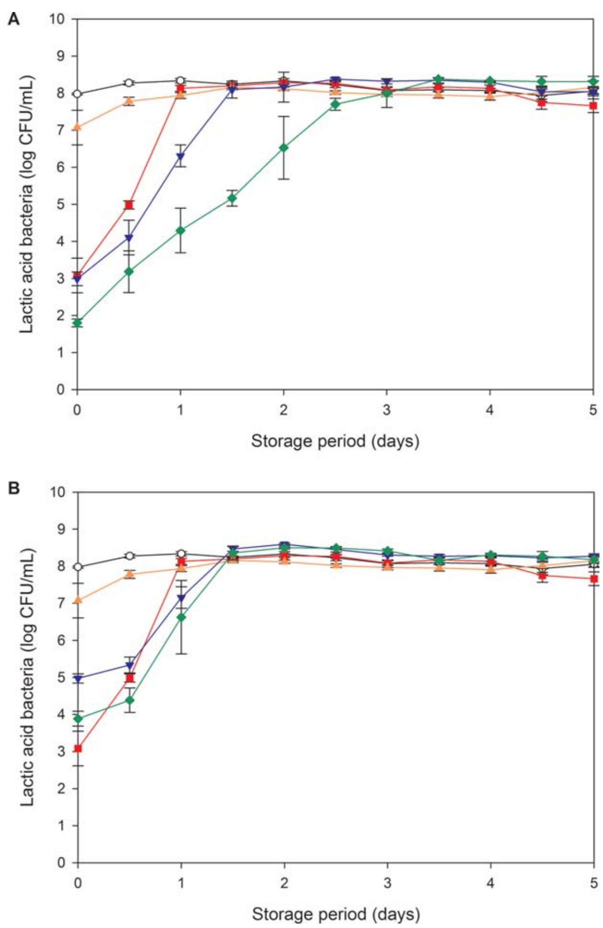

FIG. 3. EFFECTS OF COMBINED TREATMENTS OF A TEFLON-COIL UV-C WITH HHP (UV-HHP) AT (a) 400 MPa and (b) 500 MPa ON INACTIVATION OF LAB IN DONGCHIMI JUICE DURING STORAGE AT 25C

No treatment (○), UV alone (▲), heat treatment (■), HHP alone (▼), UV-HHP combined (◆). Error bars represent mean ± standard deviation ($n = 3$).

UV-C light is largely absorbed by the DNA of a microorganism, resulting in prevention of both DNA transcription and translation via adjacent pyrimidine base bonding on the same DNA strand. Furthermore, application of UV-C light is a dry and cold process that does not leave any chemical residue on a product. Another advantage of UV-C light is a reasonable operational cost, in comparison with other disinfection methods. However, the presence of color compounds, organic solutes and suspended matter in liquid foods particularly in liquid products and beverages transmits relatively little UV light, and this low transmission decreases the performance efficiency of the UV pasteurization (Koutchma 2009; Liu *et al.* 2015). The penetration depth of UV light in juices is relatively very low that most of the radiation is absorbed within a few millimeters (Feng *et al.* 2013). Food matrix and mixing system are important factors during UV processing (de Souza *et al.* 2015). Hence, the efficiency of a radiation treatment system is highly dependent on effective process engineering. UV-C reactors with different design modification have been proposed for pasteurization of fresh fruit juices (Koutchma 2009). Based on the Lambert-Beer law, absorption of UV light is dependent on the wavelength and the concentration of the absorbing substance. For cloudy juices with a low UV penetration depth, "Dean vortices" and secondary eddy flow effects can be achieved for liquid flow in a coiled tube (Dean 1927; Koutchma 2009). Considering such important factors, a helically wound Teflon-coil was used in this study to achieve secondary whirlpool flow. This type of liquid flow generates secondary vortices, known as "Dean vortices or effect," that permit radical fluid mixing even in a laminar flow field and promotes maximum UV exposure for all elements in the liquid (Dean 1927; Müller *et al.* 2011; Feng *et al.* 2013).

Geveke (2008) reported the development of a small-scale UV system consisted of low-pressure mercury bulbs surrounded by UV transparent tubing for inactivation of *Escherichia coli* K12 in liquid egg white. de Souza *et al.* (2015) reported the use of a novel UV-C rector equipped with Teflon-coil tube for decontamination of liquid egg products. Liu *et al.* (2015) reported the application of a novel setup using water assisted UV processing to overcome the UV limitations of low penetration for microbial inactivation on fresh blueberries. Blueberries were immersed and rotated in agitated water to achieve a more uniform exposure to UV light. In present study, lower reductions in LAB counts in dongchimi juice by UV-C alone treatment might be because UV light can penetrate in liquid food surfaces to a very short depth (Koutchma 2009; Liu *et al.* 2015). Hence, one promising alternative for increasing the microbial inactivation efficiency during the processing of foods is use of combined treatments to achieve a synergistic inactivation effect (Noci *et al.* 2008; Chai *et al.* 2014; Yoo *et al.* 2015; Shahbaz *et al.* 2016a).

The effectiveness of HHP for inactivation of microorganisms in fresh juices has been reported (Juarez-Enriquez *et al.* 2015). High-pressure processing probably induces changes in cell morphology, biochemical reactions and thermotropic phase in cell membrane lipids, and loss of microbial genetic functions (Goh *et al.* 2007; Georget *et al.* 2015). Furthermore, the efficacy of an HHP treatment is dependent on the microorganism, and the composition of a food matrix. High concentrations of sugars and salts in food products can exert a baroprotective effect on microorganisms (Goh *et al.* 2007; Considine *et al.* 2008). Manas and Pagan (2005) reported that sucrose protects bacterial cells against HHP pressure damage based on stabilization of the functionality of membrane proteins. Seasoning mixtures used in preparation of dongchimi can contribute to bacterial baroprotection during HHP treatment. However, resistance to pressure varies considerably between species and among strains within a species, as well as on the bacterial physiological state (Considine *et al.* 2008; Georget *et al.* 2015). HHP is a powerful technique for pasteurization of microorganisms in liquid foods. However, a single HHP process generally requires high-pressure levels to produce sterilize products. High-pressure levels such as above 500 MPa with prolonged holding times during repeated process cycles lead to wear-and-tear on equipment and expense on power and labor due to operating and maintenance costs (Chen and Hoover 2003; Koutchma 2012).

Microbial inactivation patterns in the current study indicated that some bacteria in dongchimi juice were more resistant to HHP alone treatments at pressure levels of 400–500 MPa. Therefore, an effective strategy for increasing the microbial inactivation efficiency during food processing is hurdle approach or combined treatments (Noci *et al.* 2008; Palgan *et al.* 2011; Chai *et al.* 2014; Yoo *et al.* 2015; Shahbaz *et al.* 2016a). A combination of UVC/TiO_2 photocatalysis and HHP at 550 MPa for 90 s completely inactivated natural yeast/molds, coliforms and *Pseudomonas* in *Angelica keiskei* juice (Chai *et al.* 2014). Enhanced reduction of microbial populations in apple juice was reported based on a synergistic action of UV and pulsed electric fields (Noci *et al.* 2008). UVC/TiO_2 photocatalysis successfully inactivated microorganisms in the Korean malt-and-rice traditional drink sikhye and, hence, increased the shelf life of the product (Shahbaz *et al.* 2016b).

The efficacy of combined treatments for inactivation of bacterial cells also depends on other factors, such as the number of treatment cycles, the bacterial growth phase, pH, the pressure holding time and temperature (Considine *et al.* 2008). The possible increase in the bacterial counts over storage might be due to the resuscitation of sublethally injured cells after the inactivation treatment (Wu 2008). The synergistic inactivation of microorganisms in sequential treatment might be due to a multiple damage mechanism

TABLE 1. CHANGES IN pH VALUES OF DONGCHIMI JUICE TREATED WITH A TEFLON-COIL UV-C, HHP AND UV-HHP COMBINED TREATMENTS WITH STORAGE AT 25C

	Storage period (days)					
Treatment	0	1	2	3	4	5
No treatment	4.16 ± 0.01^{aD}	3.69 ± 0.02^{aC}	3.52 ± 0.02^{aB}	3.45 ± 0.03^{aA}	3.42 ± 0.03^{aA}	3.45 ± 0.06^{bA}
UV-C	4.14 ± 0.01^{aD}	3.86 ± 0.12^{bC}	3.63 ± 0.02^{bB}	3.55 ± 0.03^{bcAB}	3.47 ± 0.06^{bcA}	3.49 ± 0.02^{bA}
Heat	4.12 ± 0.01^{aD}	4.43 ± 0.01^{cE}	3.67 ± 0.02^{bC}	3.53 ± 0.01^{bcB}	3.51 ± 0.03^{cAB}	3.49 ± 0.03^{bA}
HHP400	4.72 ± 0.03^{eD}	5.05 ± 0.07^{fE}	3.84 ± 0.16^{cC}	3.50 ± 0.04^{abB}	3.46 ± 0.01^{abB}	3.34 ± 0.03^{aA}
UV-HHP400	4.68 ± 0.01^{dD}	4.93 ± 0.08^{eE}	3.78 ± 0.01^{cC}	3.58 ± 0.10^{cB}	3.51 ± 0.01^{cB}	3.30 ± 0.06^{aA}
HHP500	4.57 ± 0.01^{cE}	4.70 ± 0.03^{dF}	4.42 ± 0.14^{dD}	3.83 ± 0.01^{dC}	3.69 ± 0.02^{dB}	3.58 ± 0.08^{cA}
UV-HHP500	4.42 ± 0.00^{bB}	4.64 ± 0.01^{dC}	4.63 ± 0.05^{eC}	4.44 ± 0.02^{eB}	3.75 ± 0.05^{eA}	3.68 ± 0.07^{dA}

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

caused by two different inactivation treatments resulting in different types of injuries to cell structures (Smigic and Rajkovic 2014; Shahbaz *et al.* 2016a).

Changes in pH and Titratable Acidity

The early stage pH value of untreated dongchimi juice was 4.16, which quickly fell to 3.69 after 1 day of storage at room temperature (Table 1). UV-C alone treated samples also showed a similar decrease in pH values. In contrast, no change in the pH value of dongchimi juice was observed 2 days after heat treatment, 3 days after HHP alone treatment at 500 MPa and 4 days after UV-HHP combined treatment at 400–500 MPa (Table 1). Thus, HHP treatment in combination with UV-C retained the pH value of dongchimi juice for a longer period. An analogous pattern of change was observed for the titratable acidity values of dongchimi juice during storage (Table 2).

Acidity and pH are important parameters for evaluation of food preservation methods. The food decomposition process by any means, including hydrolysis, oxidation and fermentation, changes the hydrogen ion concentration and, consequently, the food acidity level (Queiroz *et al.* 2010). The efficiency of HHP treatments for preservation of fruit juice without a significant effect on the basic juice composition has been reported (Juarez-Enriquez *et al.* 2015). HHP has been reported to extend the shelf life of food while maintaining the sensory properties of fresh food products (Considine *et al.* 2008). In a study reported by Queiroz *et al.* (2010), HHP treatment at 250–400 MPa for 3–7 min did not change pH and titratable acidity values of cashew apple juice, in agreement with present results. Barba *et al.* (2013) found no significant changes in pH or in the soluble solids content of blueberry juice treated with pressure levels of 200–600 MPa for 5–15 min, in agreement with present findings.

Changes in the Content of Organic Acids

Organic acids play a significant role in taste, flavor and consumer acceptance of beverages. Lactic acid was the predominant organic acid in untreated dongchimi juice. Cho *et al.* (2015) also reported that lactic acid was the major organic acid in dongchimi, similar to our results. Malic acid, acetic

TABLE 2. CHANGES IN THE TITRATABLE ACIDITY OF DONGCHIMI JUICE TREATED WITH A TEFLON-COIL UV-C, HHP AND UV-HHP COMBINED TREATMENTS WITH STORAGE AT 25C

	Storage period (days)					
Treatment	0	1	2	3	4	5
No treatment	0.08 ± 0.00^{bcA}	0.20 ± 0.02^{dB}	0.40 ± 0.02^{eC}	0.46 ± 0.02^{fD}	0.50 ± 0.01^{fE}	0.48 ± 0.03^{bDE}
UV-C	0.06 ± 0.00^{aA}	0.18 ± 0.05^{cB}	0.40 ± 0.01^{dC}	0.40 ± 0.01^{deD}	0.41 ± 0.02^{dD}	0.48 ± 0.02^{bE}
Heat	0.06 ± 0.00^{aA}	0.07 ± 0.00^{aA}	0.25 ± 0.01^{cB}	0.32 ± 0.01^{cC}	0.33 ± 0.01^{cC}	0.32 ± 0.01^{aC}
HHP400	0.08 ± 0.01^{bcA}	0.10 ± 0.00^{bA}	0.25 ± 0.04^{cB}	0.41 ± 0.02^{eC}	0.44 ± 0.03^{eD}	0.54 ± 0.01^{cE}
UV-HHP400	0.06 ± 0.00^{aA}	0.10 ± 0.01^{bB}	0.21 ± 0.05^{bC}	0.38 ± 0.01^{dD}	0.42 ± 0.02^{deE}	0.50 ± 0.06^{bcF}
HHP500	0.08 ± 0.00^{dA}	0.09 ± 0.01^{bA}	0.13 ± 0.02^{aA}	0.26 ± 0.02^{aB}	0.29 ± 0.04^{bB}	0.35 ± 0.05^{aC}
UV-HHP500	0.07 ± 0.00^{bA}	0.09 ± 0.01^{bA}	0.11 ± 0.00^{aA}	0.10 ± 0.05^{aA}	0.26 ± 0.03^{aB}	0.32 ± 0.06^{aC}

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

TABLE 3. CHANGES IN THE CONTENT OF ORGANIC ACIDS IN DONGCHIMI JUICE TREATED WITH A TEFLON-COIL UV-C, HHP AND UV-HHP COMBINED TREATMENTS

	Organic acid content (mg/mL)			
Treatment	Lactic acid	Malic acid	Acetic acid	Ascorbic acid
No treatment	4.35 ± 1.88[a]	0.55 ± 0.41[a]	0.35 ± 0.14[abc]	0.120 ± 0.017[b]
UV-C	5.01 ± 2.01[a]	0.61 ± 0.07[a]	0.45 ± 0.18[c]	0.045 ± 0.011[a]
Heat	4.48 ± 0.80[a]	0.67 ± 0.38[a]	0.38 ± 0.08[abc]	0.057 ± 0.010[a]
HHP400	5.00 ± 1.81[a]	0.55 ± 0.38[a]	0.37 ± 0.12[abc]	0.054 ± 0.010[a]
UV-HHP400	5.72 ± 1.56[a]	0.60 ± 0.40[a]	0.42 ± 0.07[bc]	0.064 ± 0.003[a]
HHP500	4.09 ± 1.26[a]	0.62 ± 0.20[a]	0.17 ± 0.07[a]	0.057 ± 0.008[a]
UV-HHP500	4.27 ± 0.73[a]	0.44 ± 0.20[a]	0.23 ± 0.02[ab]	0.049 ± 0.005[a]

Values are expressed as a mean ± standard deviation ($n = 3$).
Different lower case letters in the same column for each day indicate significant differences among treatments ($P < 0.05$).

acid and ascorbic acid were found in a comparative lower concentrations in untreated dongchimi juice. The ascorbic acid content in dongchimi juice was significantly decreased after all applied treatments compared with untreated samples. However, the juice samples subjected to UV-HHP combined treatment suffered a comparatively less reduction in the ascorbic acid content than other treated samples (Table 3). Lactic acid and acetic acid contents were reduced but within the same statistical range at HHP alone and UV-HHP combined treatment at 500 MPa. In contrast, malic acid content was slightly decreased affected without a statistical difference at all treatment conditions (Table 3). Malic acid content remained stable in milk-and-soy smoothies after HPP treatment at 450 and 550 MPa supporting our results. Furthermore, the storage period did not significantly affect the organic acid content in process smoothies (Andrés *et al.* 2016).

Rao *et al.* (2014) found that HHP treatment at 400–600 MPa was more useful for preservation of the ascorbic acid content in peach juice than thermal processing. A decrease in the ascorbic acid content of dongchimi juice can be primarily attributed to ascorbic acid instability under heat and nonthermal processing. Moltó-Puigmartí *et al.* (2011) also found that the ascorbic acid content in human milk was better retained after HHP than after thermal pasteurization. Better retention of ascorbic acid levels using high-pressure processing rather than thermal treatment was also reported by Patras *et al.* (2009) for strawberry and blackberry purées. Furthermore, a longer holding time was more important than the pressure level for reduction in the vitamin C content during high-pressure pasteurization of fruit and vegetable juices (Houska *et al.* 2006). A long HHP treatment duration may expose ascorbic acid to reaction with oxygen for a longer time. The use of a higher pressure with a shorter holding time for preservation of the vitamin C content of fruit and vegetable juices was also supported by Houska *et al.* (2006).

Sensory Qualities of Dongchimi Juice

Mean values of response scores from sensory panelists are shown in Table 4. In general, untreated control samples attained the highest score for flavor, taste, color and overall acceptability. Nonthermal treated samples received slightly lower preference scores without a statistically significant difference on day 0, compared with untreated control juice samples. On the other hand, heat treated samples received the lowest preference scores immediately after treatment and after 5 days of storage. In contrast, panelists reported significantly ($P < 0.05$) higher preference scores for

TABLE 4. EFFECTS OF HHP, AND UV-HHP COMBINED TREATMENTS, AND HEAT TREATMENT ON SENSORY CHARACTERISTICS OF DONGCHIMI JUICE STORED AT 25C

	Flavor		Taste		Color		Overall preference	
Treatment	Day 0	Day 5	Day 0	Day 5	Day 0	Day 5	Day 0	Day 5
No treatment	3.81 ± 1.17[a]	2.48 ± 0.80[a]	3.16 ± 1.00[ab]	2.47 ± 0.67[a]	3.13 ±0.72[b]	2.34 ± 0.6[a]	3.46 ± 0.78[a]	2.40 ± 0.68[a]
Heat	3.13 ± 0.96[a]	2.58 ± 0.67[a]	2.84 ± 1.00[a]	2.03 ± 0.80[a]	2.13 ±0.85[a]	2.05 ± 0.80[a]	2.94 ± 1.15[a]	2.43 ± 1.04[a]
HHP500	3.45 ± 0.88[a]	3.49 ± 0.83[b]	3.88 ± 1.06[bc]	3.58 ± 0.72[b]	3.47 ± 0.60[b]	3.60 ± 0.71[b]	3.48 ± 0.89[a]	3.42 ± 0.79[b]
UV-HHP400	3.55 ± 0.85[a]	3.61 ± 0.72[b]	3.97 ± 0.91[c]	3.61 ± 0.62[b]	3.52 ± 0.68[b]	3.26 ± 0.68[b]	3.44 ± 1.06[a]	3.39 ± 0.95[b]
UV-HHP500	3.58 ± 0.81[a]	3.49 ± 0.92[b]	3.81 ± 0.98[bc]	3.48 ± 0.62[b]	3.63 ± 0.68[b]	3.42 ± 0.50[b]	3.49 ± 0.98[a]	3.45 ± 0.57[b]

Sensory scores were based on a 5-point scale of 5 = like extremely to 1 = dislike extremely.
Values are expressed as mean ± standard deviation ($n = 30$).
Different lower case letter in the same column for each day indicate significant differences amongst treatments ($P < 0.05$).

nonthermal treated juice samples on day 5 of storage, compared with untreated control juice, in consistent with the results of chemical and microbial analyses (Table 4).

Flavor is a decisive factor in determining consumer acceptance of a particular food product. The sour and tangy taste of kimchi has been recently placed among the top five popular future flavors (Hensel 2014). Thermal treatments generally cause undesirable changes in food flavor (Juarez-Enriquez *et al.* 2015; Andrés *et al.* 2016; Shahbaz *et al.* 2016b). Nonthermal UV-HHP combined treatments effectively maintained the taste, flavor and overall acceptability of dongchimi juice upon room temperature storage, compared with untreated and heat treated samples. Results of this study were in close agreement with the recent report of Shahbaz *et al.* (2016b) where a higher sensory preference was reported for Korean traditional malt-and-rice drink sikhye treated with nonthermal UVC/TiO_2 photocatalysis method, compared with heat treatment. Andrés *et al.* (2016) reported that aroma and overall acceptability scores were significantly decreased in milk-and-soy smoothies after traditional thermal pasteurization, compared with high-pressure processing. Results of this study showed that nonthermal processing treatments did not affect the characteristic taste and flavor of dongchimi juice, which has been considered a major problem in maintaining the quality of this product at room temperature during storage.

CONCLUSION

Nonthermal UV-HHP combined treatment inhibited LAB growth due to a synergistic inactivation effect, maintained the characteristic product quality and resulted in a prolonged storage period of dongchimi juice at room temperature. The use of a Teflon-coil reactor helped to create a secondary eddy flow for a greater UV exposure to all elements in the fluid. Chemical quality parameters of pH, titratable acidity and organic acids were effectively maintained during storage after UV-HHP combined treatment, compared with traditional heat treatment. Sensory panelists reported a significantly ($P < 0.05$) higher preference for nonthermal treated juice samples over untreated and heat treated juice samples on day 5 of storage. Hence, use of UV-HHP combined treatment showed potential for controlling over-ripening in dongchimi juice during storage at room temperature with a minimum impact on characteristic quality, providing commercialization opportunities for this product at room temperature. The existence of synergy between HHP and UV light is promising for manufacturing of such fermented vegetables products. Application of UV-HHP combined treatment can be applied to a variety of other fermented fruit and vegetables products where the issues of over-ripening and a short shelf life under room temperature storage exist. The synergistic effect observed by combination treatments extends the possibility to design research studies based on combined treatments for pasteurization of liquid foods with high UV absorbability.

ACKNOWLEDGMENT

This research was supported by the High Value-added Food Technology Development Program (No. 111139-3), Ministry of Agriculture, Food and Rural Affairs, South Korea.

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