**Effect of high hydrostatic pressure processing on the background microbial loads and
quality of cantaloupe puree †**

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Running Title: High pressure treatment for preservation of cantaloupe puree

Abstract

The objective of this study was to investigate and evaluate the effects of high hydrostatic pressure (HHP) applied to cantaloupe puree (CP) on microbial loads and product quality during storage for 10 days at 4°C. Freshly prepared, double sealed and double bagged CP (ca. 5 g) was pressure treated at 300, 400 and 500 MPa at 8 °C and 15 °C for 5 min. Microflora populations, soluble solid content, pH, color, antioxidant activity, appearance and aroma were measured at 1, 6, and 10 d of storage. Results showed that high pressure treatment of 300 MPa (8 °C and 15 °C) resulted in reduction of total aerobic plate count from 3.3 to 1.8 log CFU/g. The treatment reduced the populations of native aerobic plate count to non-detectable levels (detection limit 1 log CFU/g) at 400 MPa and 500 MPa pressures at 15 °C. Pressure treatment completely inactivated mold and yeast in puree below the limits of detection at day 1 and no regrowth was observed during 10 days of storage at 4 °C while mold and yeast in untreated puree survived during the storage. High pressure treatment did not show any adverse impact on physical properties as soluble solid content (SSC, 11.2 °Brix) and acidity (pH, 6.9). The instrumental color parameters (L*, a*, b*) were affected due to HHP treatment creating a slightly lighter product, compared to control, as indicated by higher L* and lower a* values. However the change was not detected by the sensory panel while evaluating appearance scores. Pressure treatment did not affect the antioxidant capacity of puree product compared to control. Visual appearance and sniffing aroma test by panel revealed no adverse changes in the sensory parameters as a result of HHP treatment. HHP method described in this study appears to be a promising way to inactivate spoilage microorganisms in the cantaloupe puree and maintain quality. This study provides a viable option for preservation and marketing this product.

Keywords: cantaloupe puree, high pressure processing, microbial load, quality

1. Introduction

Consumption of fresh fruit and vegetables and their products increased steadily over the past decade due to their health related benefits (Ignarro, et al., 2007; Martin et al., 2002; Wells and Buzby, 2008). Cantaloupe is one of the most popular fruits in the United States and worldwide (Ukuku, et al., 2005). It contains a wide variety of antioxidant and anti-inflammatory phytonutrients, including carotenoids such as alpha-carotene, beta-carotene, lutein, beta-cryptoxanthin and zeaxanthin. It is a good source of flavonoid, phenolic acids, vitamins A, C, potassium and has high water content with a low caloric value (Laur and Tian, 2011; Ismail et al., 2010; Gil et al., 2006). Production, consumption and trade of this fruit increased due to its high nutritive value as well as its desirable taste, texture and versatility. The inherent characteristics of this fruit render them susceptible to contamination. Since melons are grown at ground level, their outer skins can be contaminated with pathogenic and spoilage bacteria during production and processing (Bowen et al., 2006; Richards and Beuchat, 2005a, b). Cantaloupe, being the most netted varieties of melons, presents a greater risk of transmission of microorganisms during food preparation as the flesh and pulp is likely to be contaminated with bacteria during cutting process. The global melon consumption represents 28 million tons per year. Worldwide, the United States is one of the largest consumers of melons, eating an average of 27 pounds of melons per year (Boriss et al., 2014). Melon consumption has increased worldwide for a variety of reasons including consumer's health consciousness. However, with the increase in consumption, the food borne illness from melon also increased (CDC, 2006). Since 1990, more than twenty-five outbreaks have been linked to cantaloupes (Bowen et al., 2006; Barak et al., 2003; CDC, 1991; FDA. 2001; Tamplin, 1997). Microorganisms are able to survive in the low acid environment of melon and grow rapidly to high levels before spoilage is

apparent (Castillo et al., 2009). Cantaloupe has a brief harvest period and large amounts of cantaloupes rot away every year in the farmlands due to the lack of processing techniques (Rastogi, 2013). Cantaloupe's flesh and pulp has a short shelf life. There is an increased market interest in cantaloupe product. Suitable processing method is needed for preservation of this fruit to extend shelf life, maintain quality and to minimize the waste. Cantaloupe can be preserved in juice or pureed form. Ma et al. (2010) suggested HHP for processing and preservation of cantaloupe juice. Due to a recent industrial inquiry, we undertook a study to investigate a method for preservation of cantaloupe as puree. Since cantaloupe flesh is very heat sensitive (Rastogi et al., 2007), thermal processing was not considered as the heat can adversely affect the color, nutrients and characteristic flavor of fruits (Cao et al., 2011). HHP treatment, as a nonthermal option, was considered for its efficacy on microbial safety and quality of food.

High pressure treatment is one of the most attractive non-thermal processing options. It has the potential to produce high quality foods that are microbiologically safe and with an extended shelf-life (Patterson, 2005). HHP processing of plant products is gaining popularity in the food industry because of its ability to inactivate microorganisms and some enzymes near room temperature with little impact on flavor or nutritional attributes of the food (Bala et al., 2008; Oey et al., 2008; Baron et al., 2006; Bayındırlı et al., 2006; Katsaros et al., 2010; Verbeyst et al., 2010; Hiremath and Ramaswamy, 2012). HHP employs elevated pressures of approximately 300-700 MPa for periods of approximately 30 s to a few minutes to destroy natural microorganisms including mold and yeast that causes spoilage of food, pathogenic bacteria and vibrio (Jofre et al., 2010; Manas & Pagan, 2005; Munoz et al., 2007). Spoilage organisms, as bacteria, mould and yeast, vary in their response to pressure, depending on factors such as species, strain, processing temperature and substrate (Patterson, 2005). Inactivation of

microorganisms by HHP is due to a number of reasons including changes in cell wall, cell membrane lipids, and cell morphology, dissociation of ribosome, loss of genetic functions and altered biochemical reactions (Ritz et. al, 2000; Wouters et al., 1998). During high pressure processing, low energy covalent bonds of treated materials or food samples appeared to be unaffected suggesting that primary structure and low-molecular-weight molecules, such as those responsible for the sensory and nutritional qualities of food, are left intact (Considine et al., 2008, Patterson, 1999). High pressures has been employed successfully to preserve purees of tomato (Knockaert, et al., 2012; Viljanen et al., 2011; Iizuka et al., 2013), carrot (Patras, 2009a), apple (Keenan, et al., 2011; Landl, et al., 2010), plum (Garcia-Parra, et al., 2014), pineapple (Chakraborty et al., 2015), blackberry (Patras et al., 2009b) and strawberry (Huang et al., 2013; Bodelon et al., 2013; Marszałek, et al., 2015). The HHP followed by chilled storage was reported to extend the shelf-life of kiwi puree while maintaining its overall quality (Fernandez-Sestelo et al., 2013). No information is available in the literature regarding the effect of high pressure treatment on the quality and fate of spoilage micro flora in cantaloupe puree product.

Previously we reported the high pressure inactivation characteristics of pathogens in cantaloupe puree (Mukhopadhyay et al., 2016). Hence, the objectives of the present research were (i) to assess any quality changes of the cantaloupe puree, due to HHP and during post-HHP storage, and (ii) to investigate the effect of HHP on the survival of aerobic organisms, yeasts and molds and their possible regrowth during refrigerated storage. To the best of our knowledge, this is the first report describing the effects of HHP treatment on the background microbial loads and the quality of processed cantaloupe puree.

2. Material and Methods

2.1. Preparation of cantaloupe purees (CP)

Cantaloupes (*Cucumis melo L. var. cantalupenis Naud*) were purchased at a local grocery store the day before each experiment and stored at 4 °C until use. Cantaloupes used in experiments were ripe with no visible microbial growth or visible physical defect. A medium size ripe cantaloupe (approx. 1380 g) was cut in half using a sterile knife. The outer rind and the seeds were removed and the flesh was diced into small cubes. The cubes were then blended in 100 g batches in a large blender for about 1 min on high setting. Blended batches were mixed together and reblended for 30 s to a consistent homogeneous puree.

2.2. High Hydrostatic Pressure treatment of cantaloupe puree

Cantaloupe puree was placed into individual sterile stomacher bags, double-sealed and double-bagged (ca. 5 g/bag). Samples were then pressure-treated at levels ranging from 300 to 500 MPa (in 100 MPa increments) for 5 min at 8 °C and 15 °C using a laboratory-scale pressure unit (Mini Food lab FPG5620, Stansted Fluid Power Ltd., Essex, UK), where heat transfer fluid (a mixture of ethanol and castor oil) continuously circulated through a refrigerated liquid chiller (Proline RP 855, Lauda, Germany) to maintain temperature. The initial temperature in the processing chamber with samples was 8 °C and 15 °C and reached a maximum of 35 °C at the highest working pressure (500 MPa). The pressure come-up rate was approximately 100 MPa /15 s and the pressure release was rather fast (~100 MPa/8 s). Pressurization time reported in this study did not include the pressure-come-up or release times. The chamber temperature was recorded by a built-in sensor (a T-type thermo couple) which was calibrated against a standard mercury thermometer with accuracy ± 0.5 °C. The temperature sensor was immersed in the

working chamber close to puree samples, which was filled with the recirculation fluid. All HHP treatments were conducted in duplicate in random mode and three samples were analyzed in each experimental replication. After pressure treatments, cantaloupe puree samples were cooled on ice and analyzed for microbial loads as per method described in Section 2.3. Samples were also stored in a refrigerator at $4 \pm 1^\circ\text{C}$ to examine the impact of HHP on the quality and the population of total aerobic bacteria, yeasts and molds during refrigerated storage for up to 10 days.

2.3. Microbial enumeration

High pressure treated or untreated samples were analyzed to recover the native microbial population by adding 0.1% sterile peptone water (PW) to each bag containing sample in 1:8 ratio (wt: vol.). The mixture was pummeled in a Stomacher 400 laboratory blender (Seward, Worthington, UK) for 2 min at 230 rpm to obtain a homogenate. Decimal serial dilutions of the homogenate were then prepared in 0.1% PW (pH 6.9). Surviving native microbial populations in puree samples were evaluated by spread plating 0.1 mL (in duplicate) on to a range of media. Total plate count (TPC) of aerobic organisms were enumerated by plating on plate count agar (PCA, BD Difco) with incubation at 37°C for 24-48 h, and mold and yeast (M&Y) were enumerated on dichloran rose bengal chlortetracycline agar (DRBC, BD Difco) with incubation at 25°C for 5 days. The experiments were conducted three times with duplicate determination of colony forming units (CFU).

2.4. Color analysis

To assess the effect on quality HHP experiments were conducted in triplicate at each experimental pressure and temperature. Control and HHP treated puree samples were stored in a refrigerator at $4 \pm 1^\circ\text{C}$. Various quality parameters (color, visual and aroma, soluble solids, pH, Brix, and antioxidant capacity) of control and pressure treated puree were determined at 1, 6 and 10 d of storage. Color (CIE L^* , a^* , b^*) was measured using Hunter Lab Ultra Scan VIS with Easy Match QC Software, Version 4.03.00 (Hunter Associates Laboratory, Inc., Reston, VA, USA). Puree sample (ca. 7.5 g) was placed into the 10 mm cell and the Hunter Lab values (L^* , a^* and b^*) were measured using Mode #6 RSEX (Reflectance Specular Excluded), 0.375 inch measuring aperture, with D65/10 illuminant-viewing geometry. Experiments were conducted in triplicate at each pressure with duplicated samples analyzed for each experimental pressure. Hue and chroma values were calculated from the following equations: $\text{Hue} = \tan^{-1} (b^* / a^*)$ and $\text{chroma} = (a^{*2} + b^{*2})^{1/2}$.

2.5. Visual and Aroma analyses

For estimation of visual and aroma quality approximately 5g of treated or untreated puree samples were placed in two Souffle cups (2 oz cups, #B200 with lid # PL2, Solo Cup Company, Lake Forest, IL, USA) and the cups containing sample was placed in the refrigerator at 4°C for 30 min minutes. Visual appearance and aroma was evaluated by 4 panelists by opening the containers and sniffing the headspace as per method described by Fan et al. (2008). Duplicate samples were tested for each of three replicates. Cantaloupe puree samples (10g) were stored at -80°C to use for comparison of visual quality of samples during storage. The visual scale was set as below:

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190 9=excellent quality, characteristic orange/yellow color

191 7=good quality; slightly visible loss of orange/yellow color; not objectionable

192 5=pale color, fair; lower limit of sales appeal

193 3=poor, obvious pale/whitish discoloration

194 1=extremely poor; not usable; moldy

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196 The aroma scale was set as:

197 9=strong, characteristic cantaloupe aroma

198 7=pleasant, mild cantaloupe aroma, slightly “flat”;

199 5=bland, faint cantaloupe odor, detectable off-odor;

200 3=mild sour or other off odors;

201 1=distinct strong off-odor, fermented like.

202 Fresh puree was used as the reference (scale of 9).

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204 *2.6. Soluble Solids (BRIX) analysis*

205 Soluble solids were measured in the control and treated puree samples using a
206 refractometer (AR200 Digital Refractometer, Reichert, Inc, Depew, NY, USA) at room
207 temperature. Sample holder was cleaned and dried using deionized (DI) water and Kim wipe in-
208 between sample readings. Duplicate reading was taken for each replicate of triplicate
209 experiments. Results were expressed as °Brix.

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2.7. pH measurement

A tabletop pH meter (Orion 420A+ with Orion 9157RN triode refillable pH electrode, Thermo Electron Corporation, Waltham, MA, USA) was used to measure pH of the puree samples. Calibration of the pH meter was done prior to taking readings using the pH 3, 7 and 10 standard buffers.

2.8. Antioxidants capacity

Control and pressure treated cantaloupe puree samples (3 g) were homogenized with 3 mL of 70% methanol using a homogenizer (Virtishear, Virtis, Gardiner, NY, USA) at a speed setting of 70 for 1 min. The homogenate was filtered through 4 layers of cheesecloth, and the filtrate was centrifuged at 10,000 x g for 10 min at 4°C in a Sorvall Lynx 4000 refrigerated centrifuge (Fisher Scientific, Waltham, MA, USA). Supernatants were either analyzed for antioxidant capacity within 3 weeks storage at -76°C. Antioxidant activity in the supernatants was determined using the automated oxygen radical absorbance capacity (ORAC) method according to Fan et al. (2011). The automated ORAC assay was carried out on a BioTek Synergy HT Multi-mode Microplate Reader (Winooski, VT, USA) with a fluorescence attachment. Diluted cantaloupe puree samples (40x or 80x dilution) and blank buffer wells were run on the same plates. Fluorescent filters were set to pass light with an excitation wavelength of 485 nm and an emission wavelength of 528 nm. In the final assay, 1.5×10^{-4} L 8×10^{-8} M sodium fluorescein (fluorescent probe) was used as a target of free radical damage, 2.5×10^{-5} L [2, 2'-azobis (2-methylpropionamide) dihydrochloride] (AAPH) (4×10^{-3} M) as a peroxy radical generator, 2.5×10^{-5} L diluted supernatants as sample, and Trolox as a standard. The analyzer was programmed to record the fluorescence each min after AAPH addition. Final results were

calculated using the differences of areas under the curves between a blank and a sample and are expressed as sample, fresh weight basis. There were four measurements for each sample from one replicate, and there were a total of 16 measurements for each treatment. ORAC was expressed as Trolox equivalent (TE) ($\mu\text{mol TE}/100\text{g FW}$).

2.9. Statistical analyses

Experiments were conducted in duplicate using three cantaloupe puree samples for each treatment, per experimental design, for a total of six data points per treatment. Data were pooled and analyzed using SAS (version 9.2) statistical package (SAS Institute Inc., Cary, NC, USA) for analysis of variance (ANOVA) and the Bonferroni LSD method (Miller, 1981) to estimate significant differences ($p < 0.05$) between mean values. Significance was defined at $p < 0.05$.

3. Results and discussion

3.1. Effects of pressure treatments on the background microbial loads due to processing and during storage

Fresh produce has limited shelf life which is one of the major concerns the produce industry is facing today (Aguero et al., 2014). The background spoilage microbial populations and the factors that influence their growth play an important role in the postharvest quality of produce (Allende, et al., 2004; Soler-Rivas, et al., 1999). Cantaloupe is an aromatic fruit and is susceptible to microbial invasion due to its high nutrition and low acidity. Large amounts of cantaloupes rot away in farmlands every year due to lack of processing. Appropriate processing methods are needed for this fruit to minimize waste. Reduction in background microbial

populations in fruits and vegetables is dependent on the treatment effectiveness, produce type and the background microbial composition.

The influence of HHP treatment on the total plate count (TPC), and mold and yeast (M&Y) population in untreated and HHP treated cantaloupe puree was evaluated over 10 days of storage at 4 °C. Change in the mean total aerobic microorganism populations of the control and HHP treated puree samples over this short refrigeration period are shown in Table 1. Initially, at day 1, TPC and M&Y population in untreated cantaloupe puree was 3.3 and 1.2 log CFU.g⁻¹ respectively. This is in general agreement with the reported total aerobic microorganism population for fresh cut untreated melon (Ukuku et al., 2005). The HHP treatment (300 MPa, at 8 °C and 15 °C) significantly ($p < 0.05$) reduced the populations of native bacteria in cantaloupe puree to ca. 2 log₁₀ CFU/g during the first 6 days of storage and the population remained low (ca. 1.8 log₁₀ CFU/g) through 10 days, while the total aerobic bacteria on control samples increased significantly from 3.3 log₁₀ CFU/g at day 1 to 4.3 log₁₀ CFU/g at day 10 (Table 1). Table 1 indicates a combination of 10 days of refrigeration of HHP treated cantaloupe puree at 400 MPa and 8 °C can completely inactivate the aerobic bacterial population. TPC values in the cantaloupe puree was reduced to below the detection limit due to treatment at 400 MPa and 15 °C and 500 MPa at 8 °C and 15 °C.

Fruit and fruit products are often contaminated with fungi like molds and yeasts causing spoilage and release of off flavors and associated discoloration of the products (Tournas, et al., 2006). The survival of the fungi in HHP processed cantaloupe puree was studied and the result is provided in Table 1. The effects of 5 min HHP treatment protocols on the mold and yeast population (M&Y) were very intense. The HHP treatment completely inactivated mold and yeast in puree samples at day 1 and no re-growth was found during subsequent 10 days of

storage, while mold and yeast on the control cantaloupe puree grew from approximately 1.2 to 1.4 log₁₀ CFU/g by the end of storage period (Table 1).

Microbial inactivation by HHP depends on a combination of factors including cell type, cell membrane composition, proteins, enzymes and the food type. HHP treatment at 150 MPa for 15 min reported to reduce the total plate count (TPC) in acid fruits such as strawberry puree (pH 3-3.9) by 2.4 log CFU/g (Hsu, et al., 2014), while the treatment at 300 MPa for 2 min reduced the M&Y population to below the 1 log detection limit (Huang et al., 2013). Report on the HHP processing of cantaloupe puree is not available in the literature. However, HHP treatment (400 MPa for 10 min) for sweet potato nectar (pH 5.3-5.6), a low acid food, reduced the background TPC from 6.0 to 1.14 log CFU/g and there was little or no growth of aerobic population during 12 days storage at 4 °C. The Y&M count was reduced from 4.5 logs to under detection limit and the population remained below the detection level during the same duration at 4 °C (Wang et al., 2012). For Pumpkin, which also belongs to low acid food group, HHP treatment (350 MPa for 5 min) of the sliced pieces reduced the TPC and M&Y from 5.97 and 3.15 logs to 2.81 and 1.42 logs respectively (Zhou et al., 2014). The results presented in this study are in general good agreement with the reported findings.

HHP treatment of 300 MPa at 8 °C for 5 min effectively reduced natural yeasts and molds in cantaloupe puree to below 1 log. However, aerobic bacterial population was reduced to below detection level after 10 days storage for 400 MPa pressure treated sample. Hence HHP of 400 MPa for 5 min at 8 °C followed by 10 days refrigeration may be a viable decontamination method for the minimal processing of cantaloupe puree. This is an interesting observation. From the process economy point of view, a pressure lower than 500 MPa is very much encouraging. It might be feasible to reduce the bacterial population to below the detection level at a pressure

lower than 400 MPa, such as 300 MPa, by extending the cold (4°C) storage time period beyond 10 days. Further experiments are needed to confirm this assumption.

3.2. Effects of high pressure treatment on Soluble Solid content and pH of puree

As the ripening progresses, fruits and vegetables undergo several compositional changes, namely increase in sugar and decrease in organic acid contents, resulting in development of characteristic test, color and flavor (Kader, 2008). Food processing methods can slow or stop the progress of these changes and can alter the characteristic quality (Jordan & Seelye, 2009). High pressure processing has the potential to produce high quality foods with extended shelf life. The effect of pressure treatments (300-500 MPa for 5 min) on the instrumental acidity and soluble solid content were evaluated after processing and during refrigerated storage and results are shown Table 2. In the current study with cantaloupe puree, the comparison tests of mean values obtained from experimental data analysis for soluble solids content (°Brix) and pH yielded no significant differences for the pressurized and control samples in either of these two parameters. Also, no significant variations were observed during the 10 days refrigerated storage (4 °C). The average pH values obtained were 6.8 and 6.6 for the control and pressurized puree samples. The °Brix values, which provide an assessment of the specific gravity of the product, were 11.3 for the control and 11.4 for the pressure treated sample. This finding is in accordance with other studies on pressurized and untreated melon. Wolbang et al. (2008) investigated the impact of HHP on three commercial melon cultivars and found that high pressure treatment of cut melon pieces did not have any effect on total titratable acidity and total soluble solids. Several other reports on pressure treated fruits and vegetable products also indicated no variations in pH and °Brix values after pressure treatment and during storage (Jayachandran, et al. 2015; Huang, et al.,

2013). Biochemical reactions such as hydrolysis, oxidation, fermentation, decomposition, etc., are usually responsible for variation in acidity and soluble solid contents in fruits and products. HHP being nondestructive in nature merely distributes the equilibrium within the system without affecting the covalent bonds (Hayashi, 1989). This is probably the reason for the insignificant changes in pH and °Brix values for pressure treated cantaloupe compared to control. The °Brix and acidity (pH) are important factors in determining eating quality of fruits and vegetables. As the result presented in Table 2, both of these two factors were preserved following HHP and subsequent storage at 4 °C, indicating an advantage of the present high pressure treatment method for cantaloupe puree with respect to these two important organoleptic parameters.

3.3. Treatment effects on puree color

Color of fruits and vegetables is governed by the complex chemical, biochemical, microbial and physical changes which occur during pre- and postharvest handling and processing (Nisha et al., 2011) and its measurement is an indirect check of quality attributes since it correlates well with other physicochemical properties.

Instrumental color changes of control cantaloupe puree before and after pressure treatment and during storage are shown in Table 2. The lightness (L*) factor of processed cantaloupe puree exhibited an increasing trend with higher pressure and temperature. Increase in lightness (L*) values for pressure treated fruit purees and pulps have been reported in the literature (Landl et al., 2010; Sanchez-Moreno et al., 2006; Yen and Lin, 1996). The increase in lightness in this work could be due to the pigment cell disruption at the cantaloupe puree surface resulting in a higher lightness value. Pressure treatment had a mixed effect on chromaticity factors (a* and b*) of puree. The redness values (a*) of puree samples were unchanged by high pressure treatment

(300-500 MPa) at lower temperature (8 °C) compared to higher temperature (15 °C) when the red to green chromatic spectrum (a^*) fell significantly immediately after pressure treatment and during storage. On the contrary, the b values of the chromatic spectrum of blue to yellow of treated cantaloupe puree samples were lower significantly due to pressure treatment (300 -500 MPa) at 8 °C and remained mostly unchanged at 15 °C. Thus in the current study the effect of pressure treatment on color parameters were mixed (Table 2). The calculated Hue and Chroma values were affected differently by the treatment. Hue values were significantly lower ($p<0.05$) due to pressure treatment at 15 °C compared to control while the HHP processing effect at 8 °C, on calculated chroma values were mixed.

Visual appearance of food manifested as its color is an important quality attribute that has a strong influence on consumer food choices, perceptions and purchase behavior. Reports on HHP treatment at low and moderate temperatures indicate only a limited effect on the pigments responsible for the color of fruits and vegetables (Oey et al. 2008; Matser et al., 2004). Ahmed et al. (2005) observed that the tristimulus color parameters (L^* , a^* and b^*) of mango pulp did not change significantly during HHP and the quality parameters (a^*/b^*), chroma, and hue remained unchanged indicating the minimal effect of HHP on pigments. ~~Ma et al. (2010) reported no significant change in the aromatic profile of cantaloupe juice due to high pressures treatment.~~

While there are no published reports available on the effect of high pressure treatment on cantaloupe puree color and quality, the results presented in this work indicate the suitability of HHP method for cantaloupe product.

3.4. Treatment effect on antioxidant capacity of cantaloupe puree

Cantaloupe is a good source of antioxidants as vitamin C, vitamin E, and β -carotene and flavonoids which may be affected due to high pressure treatment conditions. Therefore cantaloupe puree samples were submitted to high pressure treatment (300 - 500 MPa at 8 -15 °C) for 5 min to assess the treatment effect on total antioxidant capacity measured as Trolox equivalent (TE, μ M Trolox/g) concentration of puree.

The antioxidant capacity of cantaloupe puree samples before and after various pressure treatments and during storage were analyzed and the result is given in Figure 1. Fresh puree sample was characterized by a value of 5.6 ± 0.8 TE concentration. This is in agreement with the reported total antioxidant capacity of melons (Selale et al., 2012). Data presented in Fig. 1 showed no significant ($p \leq 0.05$) differences in antioxidant capacity values between fresh and treated samples. Also there were no significant ($p \leq 0.05$) differences in antioxidant capacity values among treated samples in the pressure and temperature ranges studied. In addition, the TE values of pressure treated puree were very stable during 10 days of storage at 4°C. Hence, the antioxidant capacity was not affected by the high pressure treatment method indicating that the antioxidant nutrients in the cantaloupe melon are not affected by the processing conditions described. This is probably due to the fact that antioxidants are small molecular species which remains stable during high pressure treatment. Antioxidants in fruits such as lycopene remain unaffected by high pressure influence. Zhang et al. (2011) demonstrated that high pressure treatment (600–900 MPa) had no impact on the lycopene content of watermelon juice.

The results on change in antioxidant capacity due to HHP treatment is in line with other published reports. Butz et al. (2002) investigated high pressure (500 - 800 MPa at 25 °C for 5 min) stability of water soluble fraction of tomato and carrot puree and observed no major difference in the antioxidant capacity due to high pressure treatment. Igual et al. (2013) also

reported no significant change in antioxidant properties of grapefruit jam due to high pressure treatment.

3.5. Changes in fruit sensory quality

Sensory evaluation of HHP treated and untreated controls at the end of cold storage are given in Table 3 and 4. One day after high pressure treatment, none of the treatment group consistently impacted the ~~appearance~~ ~~appreance~~ of cantaloupe puree (Table 3). However, the aroma scores were lower as a result of treatment (Table 4). Day after treatment, the ~~appearance~~ ~~appreance~~ scores of all stored puree remained unchanged. ~~Appearance~~ ~~Appreance~~ scores of 500 MP~~pa~~ pressure treated samples were significantly lower compared to the respective controls both at day6 and day10 of storage except that for day 6 sample treated with 500 MP~~pa~~ at 8 °C. All ~~appearance~~ ~~appreance~~ scores were above the acceptable values (>5). Unlike appreance, aroma scores were impacted due to high pressure treatment. Aroma scores of cantaloupe puree prepared from 400 and 500 MP~~pa~~ pressure and 15 °C were significantly lower than those for the control on day 6 and day 10. However like appreance, all aroma scores were with in the acceptable range (>5).

Pressure treatment involves predominantly the rupture of non-covalent bonds and does not affect covalent bonds as in the thermal treatment. HHP is, therefore, expected to affect proteins and be less detrimental to low molecular weight food components such as amino acids, vitamins etc., responsible for characteristics appearance and aroma. As a consequence, the organoleptic and nutritional properties are retained with the process, and HHP treated food presents higher quality (Rendueles, et al., 2011). However, the complex sensory properties coexist with enzymes as polyphenol oxidase and co-factors (metal ions) and may cause degradation of fine sensory

qualities during storage especially at a high temperature if the coenzymes are not fully inactivated by the process. The extent of degradation of sensory qualities depends on the high pressure treatment condition and the fruit composition. In the case of banana puree the green color was decreased gradually in storage as a result of browning (Palou et. Al., 1999) Lambert et al. (1999) studied effect of HHP on sensory quality of strawberry puree and reported no change in hexanal content and hence the aroma profile of puree when treated at 200 and 500 MPa for 20 min at 20 C. HHP followed by chilled storage was reported to extend the shelf-life of kiwi puree while maintaining its overall quality (Fernandez-Sestelo et al., 2013). Ma et al. (2010) reported sensory evaluation of cantaloupe melon juice and observed no significant aromatic difference between high pressures treated and untreated melon juice samples. Sensory evaluation presented in this work is in general agreement with the previous published work.

4. Conclusions

Production, consumption and trade of cantaloupe increased due to its high nutritive value as well as its desirable taste, texture and versatility. Cantaloupe has a brief harvest period and large amounts of cantaloupes rot away every year in the farmlands due to the lack of processing techniques. Suitable processing methods are needed for preservation of this fruit to extend shelf life and maintain quality. High pressure treatment at 300 MPa only partially inactivated aerobic (about 1.5 log CFU/g) total plate count but completely inactivated mold and yeast counts of cantaloupe puree. At 400 MPa HHP treatment at 8 °C, the TPC was reduced by about 2 logs, but the combination of the treatment with 10 days of refrigeration resulted in inactivation of the population below the limit of detection. The physical properties of cantaloupe puree such as pH and soluble solid content (°Brix) remained unaffected by the high pressure treatments. The color

parameters were affected by the treatment. L* values were increased and a* values were decreased due to treatment indicating a lighter final product. The effect of treatment on color was not detectable by the sensory panel judges. The current HHP treatment of 400 MPa for 5 min at 8 °C followed by 10 days refrigeration may be a viable decontamination method for minimal processing of cantaloupe puree with great retention of fresh-like fruit properties. The results presented in this study indicated HHP as an alternative to traditional thermal processing for cantaloupe puree.

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References

- Aguero, M. V., Viacava, G. E., Moreira, M. R., & Roura, S. I. (2014). Delayed cooling or suboptimal storage temperatures reduce butterhead lettuce shelf-life. *International Journal of Vegetable Science*, 20, 59–77.
- Ahmed, J., Ramaswamy, H., & Hiremath, N. (2005). The effect of high pressure treatment on rheological characteristics and color of mango pulp. *International Journal of Food Science and Technology*, 40, 885–895.
- Allende, A., Aguayo, E., & Artes, F. (2004). Microbial and sensory quality of commercial fresh processed red lettuce throughout the production chain and shelf life. *International Journal of Food Microbiology*, 91, 109–117.
- Balasubramaniam V.M., Farkas, D., & Turek, E.J. (2008). Preserving foods through high-pressure processing. *Food Technology*, 11, 32–38.
- Barak, J. D., Chue, B., & Milis, D.C. (2003). Recovery of surface bacteria from and surface sanitization of cantaloupes. *Journal of Food Protection*, 66, 1805–1810.
- Baron, A., Denes, J., & Durier, C. (2006). High-pressure treatment of cloudy apple juice. *LWT Food Science Technol.*, 39, 1005–1013.
- Bayındırlı, A., Alpas, H., Bozoglu, F., & Hizal, M. (2006). Efficiency of high pressure treatment on inactivation of pathogenic microorganisms and enzymes in apple, orange, apricot and sour cherry. *Food Control*, 17, 52–58.
- Bodelon, O. G., Avizcuri, J. M., Fernandez-Zurbano, P., Dizy, M., & Prestamo, G. (2013). Pressurization and cold storage of strawberry purée: Colour, anthocyanins, ascorbic acid and pectin methylesterase. *LWT Food Science and Technology*, 52, 123–130.
- Boriss H, Brunke H, Keith M. Melon Profile [Internet]. Agricultural Marketing Resource Center. (2014). Available from: <http://www.agmrc.org/commodities-products/vegetables/melon-profile/>; accessed 11/10/2016.
- Bowen, A., Fry, A., Richards, G., & Beuchat, L., (2006). Infections associated with cantaloupe consumption: a public health concern. *Epidemiology & Infection*, 134, 675–685.
- Butz, P., Edenharder, R., Fernandez Garcia, A., Fester, H., Merkel, C., & Tauscher, B. (2002). Changes in functional properties of vegetables induced by high pressure treatment. *Food Research International*, 35, 295–300.
- Cao, X.M., Zhang, Y., Zhang, F.S., Wang, Y.T., Yi, J.Y., & Liao, X.J. (2011). Effects of high

- hydrostatic pressure on enzymes, phenolic compounds, anthocyanins, polymeric color and color of strawberry pulps. *Journal of the Science of Food and Agriculture*, 91, 877-885
- Castillo, A., Martinez-Tellez, M.A., & Rodriguez-Garcia, M. O. (2009). Melons. In G. M. Sapers, E. B. Solomon & K. R. Matthews (eds.), *The Produce Contamination Problem: Causes and solutions* (Chapter 9). Elsevier, Burlington, USA
- Centers for Disease Control and Prevention (CDC) (2006–2007). Foodborne Active Surveillance Network (FoodNet) Population Survey Atlas of Exposures. Atlanta, Georgia: Centers for Disease Control and Prevention (CDC). Available from: <http://col.st/wAoCY> ; accessed 11/10/2016.
- Centers for Disease Control (CDC). (1991). Multistate outbreak of Salmonella Poona infections-United States and Canada. *Morbidity and Mortality Weekly Report*, 40, 549–552.
- Chakraborty, S., Rao, P. S., Mishra, H. N. (2015). Effect of combined high pressure-temperature treatments on color and nutritional quality attributes of pineapple (*Ananas comosus* L.) puree. *Innovative Food Science and Emerging Technologies* 28, 10-21.
- Considine, K. M., Kelly, A. L., Fitzgerald, G. F., Hill, C., & Sleator, R. D. (2008). High pressure processing – effects on microbial food safety and food quality. *Federation of European Microbiological Societies Microbiology Letters*, 281, 1-9.
- Fan, X., Annous, B. A., Beaulieu, J. C., & Sites, J. E. (2008). Effect of hot water surface pasteurization of whole fruit on shelf life and quality of fresh-cut cantaloupes. *Journal of Food Science*, 73, M91-98.
- Fan, X., & Sokorai, K. J. B. (2011). Changes in quality, liking, and purchase intent of irradiated fresh-cut spinach during storage. *Journal of Food Science*, 76, S363-368.
- Fernandez-Sestelo, A., de Saa, R. S., Perez-Lamela, C., Torrado-Agrasar, A., Rua, M., L., & Pastrana-Castro, L. (2013). *Innovative Food Science and Emerging Technologies*, 20, 64-72.
- Food and Drug Administration (FDA). (2001). FDA survey of imported fresh produce. <http://cfsan.fda.gov/dms/prodsur6.html>/Accessed 08.28.2016.
- Garcia-Parra, J., Gonzalez-Cebrino, F., Cava, R., Ramirez, R. (2014). Effect of a different high pressure thermal processing compared to a traditional thermal treatment on a red flesh and peel plum puree. *Innovative Food Science and Emerging Technologies*, 26, 26–33.
- Gil, M.I., Aguayo, E., Kader, A. A. (2006). Quality changes and nutrient retention in fresh-cut versus whole fruits during storage. *Journal of Agricultural and Food Chemistry*, 54, 4284-4296.

- Hayashi, R. (1989). Application of high pressure to food processing and preservation: Philosophy and development. In W. E. L. Spiess & H. Schubert (eds.), *Engineering and Food*, 2 (pp. 815-826). Elsevier Applied Science, London.
- Hiremath, H. D., & Ramaswamy, H. S. (2012). High-pressure destruction kinetics of spoilage and pathogenic microorganisms in mango juice. *Journal of Food Processing and Preservation*, 36, 113-125.
- Hsu, H. Y., Sheen, S., Sites, J., Huang, L. & Wu, J. S. (2014). Effect of high pressure treatment on the survival of Shiga toxin producing *Escherichia coli* in strawberry puree. *Food Microbiology*, 40, 25-30.
- Huang, Y., Ye, M., & Chen, H. (2013). Inactivation of *Escherichia coli* O157:H7 and *Salmonella* spp. in strawberry puree by high hydrostatic pressure with/without subsequent frozen storage. *International Journal of Food Microbiology*, 160, 337-343.
- Ignarro, L. J., Balestrieri, M. L., & Napoli, C. (2007). Nutrition, physical activity, and cardiovascular disease: an update. *Cardiovascular Research*, 73, 326 - 340.
- Igual, M., Sampedro, F., Martinez-Navarrete, N., & Fan, X. (2013). Combined osmodehydration and high pressure processing on the enzyme stability and antioxidant capacity of a grapefruit jam. *Journal of Food Engineering*, 114, 514-521.
- Iizuka, T., Maeda, S., & Shimizu, A. (2013). Removal of pesticide residue in cherry tomato by hydrostatic pressure. *Journal of Food Engineering* 116, Issue 4, 796-800.
- Ismail, H. I., Chan, K. W., & Mariod, A. A. (2010). Phenolic content and antioxidant activity of cantaloupe (*cucumis melo*) methanolic extracts. *Food Chemistry*, 119, 643-647.
- Jayachandran, L. E., Chakraborty, S., & Rao, P. S. (2015). Effect of high pressure processing on physicochemical properties and bioactive compounds in litchi based mixed fruit beverage. *Innovative Food Science and Emerging Technologies*, 28, 1-9.
- Jofre, A., Aymerich, T., Bover-Cid, S., & Garriga, M. (2010). Inactivation and recovery of *Listeria monocytogenes*, *Salmonella enterica* and *Staphylococcus aureus* after high pressure treatments up to 900 MPa. *International Microbiology*, 13, 105-112.
- Jordan, R. B., & Seelye, R. J. (2009). Relationship between taste perception, density and soluble solids concentration in kiwifruit (*Actinidia deliciosa*). *New Zealand Journal of Crop and Horticultural Science*, 37, 303-317.
- Kader A. A. (2008) Flavor quality of fruits and vegetables. *Journal of the Science of Food and Agriculture*, 88, 1863-1868.
- Katsaros, G. I., Tsevdou, M., Panagiotou, T., & Taoukis, P. S. (2010). Kinetic study of high

- pressure microbial and enzyme inactivation and selection of pasteurization conditions for Valencia orange juice. *International Journal of Food Science & Technology*, 45, 1119-1129.
- Keenan, D. F., Brunton, N., Butler, F., Wouters, R., & Gormley, R. (2011). Evaluation of thermal and high hydrostatic pressure processed apple purees enriched with prebiotic inclusions. *Innovative Food Science and Emerging Technologies*, 12, 261-268.
- Knockaert, G., Pulissery, S. K., Colle, I., Buggenhout, S. V., Hendrickx, M., & Loey, A.V. (2012). Lycopene degradation, isomerization and in vitro bio accessibility in high pressure homogenized tomato puree containing oil: Effect of additional thermal and high pressure processing. *Food Chemistry*, 135, 1290–1297.
- Lambert, Y., Demazeau, G., Largeteau, A., & Bouvier, J. M. (1999). Changes in aromatic volatile composition of strawberry after high pressure treatment. *Food Chemistry*, 67, 7-16.
- Landl, A., Abadias, M., Sarraga, C., Vinas, I., & Picouet, P. A. (2010). Effect of high pressure processing on the quality of acidified Granny Smith apple puree product. *Innovative Food Science and Emerging Technologies*, 11, 557-564.
- Laur, L. M., & Tian, L. (2011). Provitamin A and vitamin C contents in selected California-grown cantaloupe and honeydew melons and imported melons. *Journal of Food Composition and Analysis*, 24, 194-201.
- Ma, Y., Hu, X., Chen, J., Zhao, G., Liao, X., & Chen, F. (2010). Effect of UHP on enzyme, microorganism and flavor in cantaloupe (*Cucumis melo* L.) juice. *Journal of Food Process Engineering*, 33, 540–553.
- Manas, P., & Pagan, R. (2005). Microbial inactivation by new technologies of food preservation. *Journal of Applied Microbiology*, 98, 1387-1399.
- Marszalek, K., Marta, M., & Sylwia S. (2015). The effect of thermal pasteurization and high pressure processing at cold and mild temperatures on the chemical composition microbial and enzyme activity in strawberry puree. *Innovative Food Science and Emerging Technologies*, 27, 48-56.
- Martin, A., Cherubini, A., Andres-Lacueva, C., Paniagua, M., & Joseph, J.A. (2002). Effects of fruits and vegetables on levels of vitamins E and C in the brain and their association with cognitive performance. *Journal of Nutrition, Health & Aging*, 6, 392 - 404.
- Matser, A. M., Krebbers, B., van den Berg, R.W., & Bartels, P.V. (2004). Advantages of high pressure sterilisation on quality of food products. *Trends in Food Science and Technology*, 15, 79–85.
- Miller, R.G., Jr. (1981). *Simultaneous Statistical Inference*. (2nd. ed.). New York: Springer-

- Verlag.
- Mukhopadhyay, S., Sokorai, K., Ukuku, D., Juneja, V., Sites, J. & Cassidy, J. (2016). Inactivation of *Salmonella enterica* and *Listeria monocytogenes* in cantaloupe puree by high hydrostatic pressure with/without added ascorbic acid. *International Journal of Food Microbiology*, 235, 77-84.
- Munoz, M., Ancos, B., Sanchez-Moreno, C., Cano, M. P. (2007). Effects of high pressure and mild heat on endogenous microflora and on the inactivation and sublethal injury of *Escherichia coli* inoculated into fruit juices and vegetable soup. *Journal of Food Protection*, 70, 1587-1593.
- Nisha, P., Singhal, R. S., & Pandit, A. B. (2011). Kinetic modeling of color degradation in tomato puree (*Lycopersicon esculentum* L.). *Food and Bioprocess Technology*, 4, 781–787.
- Oey, I., Lille, M., Van Loey, A., & Hendrickx, M. (2008). Effect of high-pressure processing on colour, texture and flavour of fruit- and vegetable-based food products: a review. *Trends in Food Science & Technology*, 19, 320-328.
- Palou, E., Lopez-Mal, A., Barbosa-Canovas, G. V., Welti-Chanes, J., & Swanson, B. G. 1999. Polyphenoloxidase Activity and Color of Blanched and High Hydrostatic Pressure Treated Banana Puree. *Journal of Food Science*, 64, 42–45.
- Patras, A., Brunton, N., Pieve, S. D., Butler, F., & Downey, G. (2009a). Effect of thermal and high pressure processing on antioxidant activity and instrumental color of tomato and carrot purees. *Innovative Food Science and Emerging Technologies*, 10, 16-22.
- Patras, A., Brunton, N. P., Pieve, S. D., & Butler, F. (2009b). Impact of high pressure processing on total antioxidant activity, phenolic, ascorbic acid, anthocyanin content and colour of strawberry and blackberry purees. *Innovative Food Science and Emerging Technologies*, 10, 308-313.
- Patterson, M. F. (1999). High-pressure treatment of foods. In R. K. Robinson, C. A. Batt, & P. D. Patel (Eds.), *Encyclopedia of food microbiology* (pp.1051-1065). New York: Academic Press.
- Patterson, M.F. (2005). Microbiology of pressure-treated foods. *Journal of Applied Microbiology*, 98, 1400–1409.
- Rastogi, N.K. (2013). High pressure processing of plant products. In N. K. Rastogi (Ed.), *Recent Developments in High Pressure Processing of Foods* (pp. 9-50). New York: Springer
- Rastogi, N. K., Raghavarao, K. S. M. S., Balasubramaniam, V. M., Niranjan, K., & Knorr,

- D. (2007). Opportunities and Challenges in High Pressure Processing of Foods. *Critical Reviews in Food Science and Nutrition*, 47, 69-112.
- Rendueles, E., Omer, M. K., Alvseike, O., Alonso-Calleja, C., Capita, R., & Prieto, M. (2011). Microbiological food safety assessment of high hydrostatic pressure processing: a review. *LWT-Food Science and Technology*, 44, 1251–1260.
- Richards, G. M., & Beuchat, L.R. (2005a). Metabiotic associations of molds and *Salmonella* Poona on intact and wounded cantaloupe rind. *International Journal of Food Microbiology*, 97, 327–339.
- Richards, G. M., & Beuchat, L. R. (2005b). Infection of cantaloupe rind with *Cladosporium cladosporioides* and *Penicillium expansum*, and associated migration of *Salmonella* Poona into edible tissues. *International Journal of Food Microbiology*, 103, 1–10.
- Ritz, M., Freulet, M., Orange, N., & Federighi, M. (2000). Effects of high hydrostatic pressure on membrane proteins of *Salmonella typhimurium*. *International Journal of Food Microbiology*, 55, 115–119.
- Sanchez-Moreno, C., Plaza, L., De Ancos, B., & Cano, M. P. (2006). Impact of high-pressure and traditional thermal processing of tomato puree carotenoids, vitamin C and antioxidant activity. *Journal of the Science of Food and Agriculture*, 86, 171–179.
- Selale, H., Sıgva, H. O., Celik, I., Doganlar, S., & Frary, A. (2012). Water-Soluble Antioxidant Potential of Melon Lines Grown in Turkey. *International Journal of Food Properties*, 15, 145-156.
- Soler-Rivas, C., Jolivet, S., Arpin, N., Olivier, J. M., & Wichers, H. J. (1999). Biochemical and physiological aspects of brown blotch disease of *Agaricus bisporus*. *Federation of European Microbiological Societies Microbiology Letters Reviews*, 23, 591-614.
- Tamplin, M., 1997. *Salmonella* and cantaloupes. *Dairy Food Environ. Sanit.* 17, 284–286.
- Tournas, V., Heeres, J., & Burgess, L. (2006). Moulds and yeasts in fruit salads and fruit juices. *Food Microbiology*, 23: 684–688.
- Ukuku, D., Bari, M. L., Kawamoto, S., & Isshiki, K. (2005). Use of hydrogen peroxide in combination with nisin, sodium lactate and citric acid for reducing transfer of bacterial pathogens from whole melon surfaces to fresh-cut pieces. *International Journal of Food Microbiology*, 104, 225–233.
- Verbeyst, L., Oey, I., Van der Plancken, I., Hendrickx, M., & Van Loey, A. (2010). Kinetic study on the thermal and pressure degradation of anthocyanins in strawberries. *Food Chemistry*. 123, 269-274.
- Viljanen, K., Lille, M., Heinio, R. L., & Buchert, J. (2011). Effect of high-pressure processing on

- volatile composition and odor of cherry tomato puree. *Food Chemistry*, 129, 1759-1765.
- Wang, Y., Liu, F., Cao, X., Chen, F., Hu, X., & Liao, X. (2012). Comparison of high hydrostatic pressure and high temperature short time processing on quality of purple sweet potato nectar. *Innovative Food Science & Emerging Technologies*, 16, 326–334.
- Wells, H. F., & Buzby, J. (2008). Dietary assessment of major trends in U.S. food consumption, 1970- 2005. *Economic Research Service, U.S. Dept. of Agriculture, Economic Information Bulletin*, 33, 7-9.
- Wolbang, C. M., Fitos, J. L., & Treeby, M. T. (2008). The effect of high pressure processing on nutritional value and quality attributes of *Cucumis melo* L. *Innovative Food Science and Emerging Technologies*, 9, 196–200.
- Wouters, P. C., Glaasker, E., & Smelt, J. P. (1998). Effects of high pressure on inactivation kinetics and events related to proton efflux in *Lactobacillus plantarum*. *Applied and Environmental Microbiology*, 64, 509-514.
- Yen, G.C., & Lin, H.T. (1996). Comparison of high pressure treatment and thermal pasteurization effects on the quality and shelf life of guava puree. *International Journal of Food Science and Technology*, 31, 205–213.
- Zhang, C., Trierweiler, B., Li, W., Butz, P., Xu, Y., Rufer, C. E., Ma, Y., & Zhao, X. (2011). Comparison of thermal, ultraviolet-c, and high pressure treatments on quality parameters of watermelon juice. *Food Chemistry*, 126, 254–260.
- Zhou, C.L., Liu, W., Zhao, J., Yuan, C., Song, Y., Chen, D., Ni, Y.Y., & Li, Q.H. (2014). The effect of high hydrostatic pressure on the microbiological quality and physical–chemical characteristics of Pumpkin (*Cucurbita maxima* Duch.) during refrigerated storage. *Innovative Food Science and Emerging Technologies*, 21, 24-34.

Figure Legends

Figure 1. Antioxidant capacity (Trolox) of cantaloupe puree as a function of pressure and temperature and storage

Figure 1

Figure 1

Figure 1. Antioxidant capacity (Trolox) of cantaloupe puree as a function of pressure and temperature and storage. Vertical error bars represents standard deviation.

Table 1.

Changes in the mean total aerobic bacterial (TPC) and mold and yeast (M&Y) populations in Control and HHP processed cantaloupe puree during 10-day refrigerated storage at 4°C. Cantaloupe puree was pressure treated at 300-500 MPa for 5 min at 8 and 15°C and then stored in a refrigerator.

Treatment Pressure (MPa)	Treatment Temperature (°C)	Storage time (day)	TPC (log CFU/g)	M&Y (log CFU/g)
Control		1	3.3±0.4aB	1.2±0.5aA
		6	3.8±0.4aA	1.3±0.1aA
		10	4.3±0.3aA	1.4±0.3aA
300	8	1	1.8±0.5bA	ND
		6	2.2±0.1bA	ND
		10	1.8±0.3bA	ND
400	8	1	1.3±0.2cA	ND
		6	1.1±0.1cA	ND
		10	ND	ND
500	8	1	ND	ND
		6	ND	ND
		10	ND	ND
300	15	1	1.6±0.5bA	ND
		6	2.1±0.3bA	ND
		10	1.7±0.2bA	ND
400	15	1	ND	ND
		6	ND	ND
		10	ND	ND
500	15	1	ND	ND
		6	ND	ND
		10	ND	ND

Data represent mean microbial population ($\log_{10}$ CFU /g) of three replicates $\pm$ 1 standard deviations.

The limits of detection were 1 log CFU/g for plating method. ND = No detectable survivor.

Data in the same column and storage day followed by the same lowercase letter are not significant different ($P>0.05$).

Data in the same column and treatment category followed by the same uppercase letter are not significantly different ($P>0.05$).

Table 2

Table 2.

Physical properties of the control and pressure-treated cantaloupe puree during 10 days refrigerated storage. Cantaloupe puree was treated at 300-500 MPa for 5 min at 8-15 °C and then stored at 4 °C.

Treatment	Storage (Days)	pH	SSC (°Brix)	L	Color a	b	Hue	Chroma
Control	1	6.9±0.3a	11.2±0.5a	21.7±1.4b	4.1±0.4a	12.1±0.1a	71.3±0.2b	12.8±0.2a
	6	6.7±0.4a	11.4±0.4a	21.2±0.2b	4.4±0.2a	12.9±0.7a	71.2±0.4b	13.6±0.2a
	10	6.8±0.4a	11.5±0.4a	21.6±1.5b	4.2±0.3a	12.7±1.2a	71.7±0.1b	13.4±0.3a
300 MPa 8°C	1	6.6±0.1a	11.2±0.4a	21.9±1.7b	4.3±0.5a	11.1±1.1b	68.8±0.4b	11.9±0.2b
	6	6.4±0.1a	11.3±0.5a	22.3±2.9a	4.3±0.5a	10.8±0.9b	68.3±0.3b	11.2±0.4c
	10	6.3±0.1a	11.5±0.4a	21.9±1.4b	4.2±0.6a	10.7±1.2b	68.6±0.2b	11.5±0.3c
400 MPa 8°C	1	6.5±0.3a	11.2±0.4a	22.1±1.4ab	4.2±0.4a	11.0±0.9b	69.1±0.2b	11.8±0.1b
	6	6.5±0.2a	11.3±0.5a	21.8±1.4b	4.2±0.7a	11.0±0.7b	69.1±0.1b	11.7±0.4b
	10	6.4±0.2a	11.4±0.4a	22.3±2.7a	4.2±0.7a	10.8±1.1b	68.7±0.3b	11.6±0.1b
500 MPa 8°C	1	6.8±0.3a	11.2±0.4a	22.1±0.7ab	4.1±0.3a	10.8±0.9b	69.2±0.3b	11.6±0.2b
	6	6.7±0.2a	11.3±0.5a	22.4±0.9a	4.3±0.3a	11.2±0.9a	69.0±0.5b	12.0±0.2b
	10	6.6±0.3a	11.3±0.4a	22.1±1.4ab	4.0±0.4a	10.6±0.7b	69.3±0.2b	11.3±0.4b
300 MPa 15°C	1	6.6±0.4a	11.4±0.6a	23.5±0.7a	3.8±0.6ab	12.5±0.3a	73.1±0.2a	13.1±0.1a
	6	6.5±0.4a	11.5±0.6a	23.7±1.3a	3.7±0.6b	11.7±1.6ab	72.5±0.2a	12.3±0.3ab
	10	6.4±0.2a	11.6±0.7a	22.5±0.7a	3.3±0.6b	10.9±0.8b	73.2±0.3a	11.4±0.4b
400 MPa 15°C	1	6.8±0.3a	11.5±0.6a	23.1±0.7a	3.7±0.3b	12.3±0.6a	73.3±0.4a	12.8±0.3a
	6	6.7±0.2a	11.5±0.6a	23.7±0.9a	3.6±0.4b	11.8±1.9a	73.0±0.2a	12.3±0.1ab
	10	6.7±0.4a	11.5±0.4a	23.1±0.6a	3.3±0.6b	11.6±0.5ab	74.1±0.2a	12.1±0.4b
500 MPa 15°C	1	6.7±0.4a	11.5±0.5a	23.4±0.9a	3.5±0.3b	12.1±0.7a	73.9±0.3a	12.6±0.2a
	6	6.7±0.4a	11.6±0.5a	23.5±0.5a	3.6±0.6b	12.3±1.6a	73.7±0.5a	12.8±0.6a
	10	6.4±0.5a	11.4±0.7a	22.8±0.4a	3.2±0.6b	11.6±0.5ab	74.6±0.4a	12.0±0.4b

Data represent mean value of three replicates±1 standard deviations.
Mean in each column not followed by the same letter are significantly different (P>0.05).

Table 3.
Effect of HHP treatment of cantaloupe puree on the appearance score during storage at 4 °C

Treatment		Appearance score during storage ^a			
Pressure	Temperature	Day1	Day6	Day10	LSD ^b
Control		8.7±0.8a	8.8±0.6a	8.5±0.5a	0.5
300 MPa	8 °C	8.5±0.9a	8.4±0.1b	8.3±0.3ab	0.6
400 MPa	8 °C	8.8±0.9a	8.5±0.3ab	8.2±0.1b	0.4
500 MPa	8 °C	8.7±0.5a	8.5±0.5ab	8.0±0.4b	0.4
300 MPa	15 °C	8.8±0.5a	9.0±0.1a	8.8±0.5a	0.5
400 MPa	15 °C	8.8±0.5a	8.7±0.9a	8.3±0.4ab	0.4
500 MPa	15 °C	8.8±0.5a	8.3±0.5b	8.1±0.5b	0.3

^a Values are means ± SD (scale of 9 to 1) (n =4). Within the same column, means with the same letter are not significantly different (P < 0.05).

^b Least significant difference at P < 0.05 for the storage effect.

Table 4.
Effect of HHP treatment of cantaloupe puree on the aroma during storage at 4 °C

Treatment		Aroma score during storage ^a			
Pressure	Temperature	Day1	Day6	Day10	LSD ^b
Control		8.3±0.5a	7.8±0.5a	7.4±0.9ab	0.2
300 MPa	8 °C	8.1±0.2a	7.9±0.5a	7.5±0.6a	0.5
400 MPa	8 °C	8.3±0.1a	7.8±0.9a	7.8±0.2a	0.4
500 MPa	8 °C	8.0±0.8ab	7.8±0.1a	7.4±0.9ab	0.4
300 MPa	15 °C	8.0±0.2ab	7.6±0.3ab	7.3±0.3b	0.5
400 MPa	15 °C	7.9±0.4ab	7.5±0.8b	7.1±0.3b	0.3
500 MPa	15 °C	7.7±0.5b	7.5±0.9b	7.0±0.8b	0.3

^a Values are means ± SD (scale of 9 to 1) (n =4). Within the same column, means with the same letter are not significantly different (P < 0.05).

^b Least significant difference at P < 0.05 for the storage effect.

Fate of microbial population subjected to High Hydrostatic Pressure (HHP)