Quality of carrot juice as influenced by blanching and sonication treatments

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ABSTRACT

A study was conducted to evaluate the influence of blanching and sonication on important quality parameters of carrot juice. Blanching of carrots was done in normal water and acidified water (45 g/L citric acid, pH 1.3) at 100 °C for 4 min and juice was extracted. Sonication of juice was done (frequency 20 KHz and amplitude level 70%) at 15 °C for 2 min. Significant increase ($P < 0.05$) was observed in total carotenoids, lycopene and lutein in blanched samples, however, this increase was more in simultaneously blanched and sonicated samples. Additionally, highest increase was observed in all these pigments as a result of combined treatment of acid blanching and sonication. Sucrose, glucose, fructose, chlorogenic acid and mineral elements (Na and K) were decreased significantly in all blanched samples while increased significantly ($P < 0.05$) in all sonicated samples. Significant decrease was observed in some minerals (P and Mg), total plate count, yeast and mold in all samples treated with blanching and sonication but this decrease was more in samples treated with acid blanching and sonication. The results suggest that combined treatment of blanching and sonication may successfully be employed for processing of carrot juice to improve quality.

1. Introduction

Carrot (*Daucus carota* L.), an important root vegetable of Umbelliferae family, is cultivated throughout the world. Carrot and its products including juices are widely accepted as a rich source of phytonutrients such as bioactive compounds, carotenoids, minerals and vitamins (Qin, Xu, & Zhang, 2005) which provide many health benefits to the human body.

Quality of an end product, in part, depends on the processing methods. Blanching is an important step for the processing of vegetables and vegetable products including juices to preserve color, inactivate enzymes and microbes, remove entrapped air and make protopectin soluble (Bahçeci, Serpen, Gökmen, & Acar, 2005; Barrett & Theerakulkait, 1995; Bourne, 1976). All these benefits of blanching depend on the heat supplied to the product but it also adversely affects the texture, heat sensitive nutrients, water soluble contents and ultimately the quality and bioactivity of the end product (Mizrahi, 1996; Wennberg, Ekvall, Olsson, & Nyman, 2006). Due to scientific evidences and increasing knowledge, consumers now want food not only with extended shelf life but also with improved quality and safety.

In order to fulfill the consumer's demand, researchers are looking for such food processing techniques that could not only retain but also improve the nutritional value of fruit juices (Bhat, Ameran, Voon, Karim, & Tze, 2011; Bhat, Kamaruddin, Min-Tze, & Karim, 2011). Sonication is such a novel non-thermal food processing technique that can meet the demands by enhancing health related nutrients and other quality attributes of fruit juices (Abid et al., 2013; Bhat, Ameran, et al., 2011; Rawson et al., 2011).

The product can be treated with ultrasound that offer improvements in these nutrients in order to recover the losses of desirable nutrients occurred during blanching, and consequently, benefits of both techniques can be obtained simultaneously. Keeping all these backdrops in focus, the present study was initiated to evaluate the effects of combined treatments of blanching and sonication on the coloring pigments (total carotenoids, lycopene and lutein), sugars (sucrose, glucose and fructose), mineral elements (Na, K, P and Mg), chlorogenic acid and microbial stability of carrot juice.

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2. Materials and methods

2.1. Chemicals

Chlorogenic acid, lutein, glucose, fructose and β-carotene were purchased from Sigma Aldrich Chemie GmbH (Steinheim, Germany). Sucrose was purchased from Fluka Chemie GmbH (Buchs, Switzerland). Formic acid and acetonitrile were obtained from Sinopharm Chemical Regent Co., Ltd (Shanghai, China). HPLC grade methanol was purchased from Hanbon Science and Technology (Jiangsu, China). Sodium sulfate was purchased from Xilong Chemical Factory (Shantou, China). Citric acid and butylated hydroxyl-toluene (BHT) were obtained from Sinopharm Chemical Regent Co., Ltd (Shanghai, China). Acetone was purchased from Lingfeng Chemical Reagent Co., Ltd (Shanghai, China). Nitric acid, hydrogen peroxide, petroleum ether and n-hexane were purchased from Nanjing Chemical Reagent Co., Ltd (Nanjing, China). All other chemicals used were of analytical grade.

2.2. Collection of raw material and blanching

Fresh good quality carrots were procured from vegetable market of Nanjing, China. Carrots were washed, peeled and sliced manually with stainless steel knife. The sliced carrots were divided into three parts. First part without blanching was selected as control, second and third parts were blanched in hot water and acidified water (citric acid of 45 g/L, pH 1.3) respectively, at 100 °C for 4 min. Then, blanched carrots were cooled to a room temperature by dipping in cold water.

2.3. Juice extraction and sonication treatment

Juice was extracted by using domestic juice extractor of MJ-M176P (Panasonic Manufacturing Berhad, Malaysia) and filtered through muslin cloth to avoid impurities and coarse particles. The juice was then sonicated (250 mL in a 500 mL jacketed vessel, 7.6 cm ID × 9.3 cm OD × 13.5 cm Depth × 14.9 cm Height) by using ultrasonic processor of 750W (VC 750, Sonics and Materials Inc., Newtown, CT, USA) with 0.5 inch probe for 2 min by adjusting the pulse duration of 5 s on and 5 s off at a frequency of 20 kHz and amplitude level of 70%. The ultrasonic intensity measured by using HI 9063 thermocouple (Hanna Instruments Ltd., Leighton Buzzard, UK) was 48 W cm^{-2}. Temperature was maintained at 15 °C by automatic control unit. The schematic diagram of exposure system is shown in Fig. 1. The ultrasound probe was immersed 2 cm in depth with respect to the liquid surface. Sonication treatments were performed in darkness to avoid any interference of light with samples and carried out in triplicate. Fresh untreated juice was selected as control. All the juice samples were stored in air tight sterilized 250 mL media bottles at 4 °C for 48 h until further analysis. The scheme of different treatments was as: control, sonicated, WB: water blanched, WBS: water blanched and sonicated, AB: acid blanched, ABS: acid blanched and sonicated.

2.4. Determination of total carotenoids

Total carotenoids were determined by the method of Liao et al. (2007) with slight modifications. Juice sample (25 mL) was taken in a separation funnel and then 80 mL of n-hexane/acetone (1:1, v/v) was added in it, shook well and held for 5 min. After separation, organic phase was extracted. Aqueous phase was repeatedly extracted by using 15 mL of n-hexane/acetone (1:1, v/v) until it became colorless. The organic phase was dehydrated by adding anhydrous sodium sulfate in it. Total carotenoids were determined at 450 nm by using a spectrophotometer (Shanghai Jinghua Science & Technology Instruments Co., Ltd, China) at ambient temperature. Standard solution of β-carotene with concentrations (2–10 μg/mL) was prepared. The results were expressed as μg β-carotene equivalent/mL of sample by plotting a standard curve.

2.5. Determination of lycopene

Lycopene was determined by using a method reported by Oliu, Serrano, Fortuny, and Belloso (2009) with some modifications. Juice sample (0.6 mL) was added to 5 mL of BHT in acetone (0.05:99.95, w/v), 5 mL of ethanol (95:5, v/v) and 10 mL of n-hexane. The mixture was centrifuged for 15 min at 320 g. After shaking, 3 mL of distilled water was added in it. The vial was then agitated for 5 min and held for 2 min to allow phase separation at room temperature. The absorbance of upper, n-hexane layer was determined using a spectrophotometer at 503 nm blanked with hexane. Following equation was used to calculate the lycopene content of each sample.

$$\text{Lycopene} = (\Delta 503 \times \text{MW} \times \text{DF} \times 1000))/(\varepsilon \times L)$$

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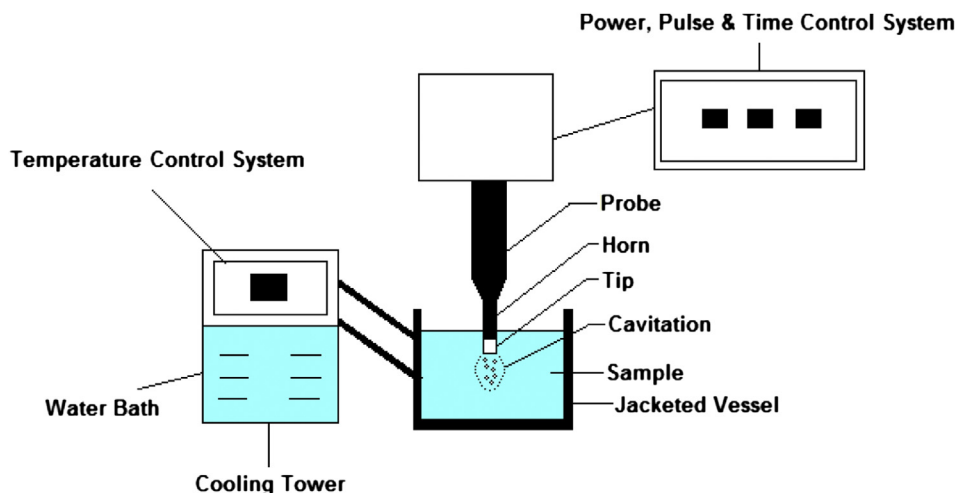

Fig. 1. Schematic diagram of probe type sonication exposure system.

cm) is the molar extinction coefficient for lycopene (Rawson et al. 2011). The Lycopene was expressed as μg/mL of samples. All measurements were taken in triplicate.

2.6. Determination of lutein

Carotenoid was extracted by using a method of Kim and Gerber (1988) with some modification. Twenty five milliliter juice was taken in a separation funnel for extraction using an equal volume of acetone for 3 times and filtered by Whatman paper No. 1, and the filter cake was re-extracted with methanol. Acetone-methanol extract was mixed vigorously with equal volume of petroleum ether. Upper petroleum ether layer was dehydrated by adding anhydrous sodium sulfate in it and after filtration it was concentrated by using a rotary evaporator (Laborota 4000-efficient, Heidolph Instruments, Germany) at 30 °C. Acetonitrile–methanol–acetone solution (40:40:20, v/v) was added in the concentrate and stored it in a dark at −18 °C for further analysis. Lutein was detected by a modified method of Kim and Gerber (1988). An Agilent 1100 series HPLC (Agilent Technologies, USA) consisted of a model G1379A degasser, a model G1311A pump, a model G1316A column oven and model G1315B diode array detection (DAD) system was used. Agilent Zorbax Eclipse XDB-C18 Column (4.6 × 150 mm, 5 μm particle size, USA) was used. The mobile phase consisted of acetonitrile–methanol–acetone (40:40:20, v/v), at a flow rate of 0.8 mL/min, and 20 μL injection volumes were used. Sample was filtered using a syringe filter of 0.45 μm diameter before injection into column and the detection wavelength was 450 nm. Content of lutein was calculated from a linear portion of a calibration curve drawn up using commercial lutein as a standard compound.

2.7. Determination of chlorogenic acid content

Chlorogenic acid content was detected by the method of Kahle, Kraus, and Richling (2005) with some modifications. An Agilent 1100 series HPLC system was used. The mobile phase consisted of aqueous formic acid (0.1:99.9, v/v) (A) and methanol (B). The gradient applied was (10:90–90:10, v/v) B in 40 min at a flow rate of 1 mL/min. Column of Agilent Zorbax Eclipse XDB-C18 was used and the injection volume of 20 μL was used. Sample was filtered by using a syringe filter of 0.45 μm diameter before injection into column. The peak was identified by comparison of retention time and UV spectra (320 nm) with that of standard. A suitable calibration curve was prepared using concentrations (10–80 μg/mL) of standard solution and the results were expressed as μg of chlorogenic acid equivalent per mL of sample.

2.8. Determination of contents of sugars (sucrose, glucose and fructose)

Sugar contents were detected by a method stated by Hurst, Martin, and Zoumas (1979). An Agilent 1100 series HPLC (Agilent Technologies, USA) consisted of a model G1379A degasser, a model G1311A pump, a model G1316A column oven and model G1315B Refractive Index Detector (RID) system was used. The mobile phase consisted of acetonitrile (75:25, v/v) and the flow rate of 1 mL/min was adjusted. Cosmosil packed column of Sugar-D (4.6 × 250 mm) was used and 20 μL sample was injected. The peaks were identified by comparison of retention times with those of authentic reference substances. Sucrose, glucose and fructose were used as standards and results were expressed as g of sucrose, glucose and fructose equivalent per liter of sample.

2.9. Analysis of mineral elements of carrot juice

Cleaning of sample containers, microwave vessel, glassware for standard and ICP samples for the determination of mineral elements was done as recommended by American Public Health Association (1998) with some modifications. In brief, all the required glassware was dipped in nitric acid solution (10:90, v/v) for up to 4 h, washed several times with distilled water and then oven dried prior to use. One milliliter juice sample was put into TFM vessel and digested with 7 mL of nitric acid solution (65:35, v/v) and 1 mL of hydrogen peroxide solution (30:70, v/v) on the microwave work station. Temperature of microwave was adjusted as 200 °C for 10 min and again 200 °C for another 10 min at 1000 W, followed by immediate ventilation at room temperature for 20 min. Then acid digested samples were shifted to 50 mL volumetric flask and diluted with pure water up to the mark. The samples were analyzed by an inductively coupled plasma-optical emission spectrometer (OPTIMATM 2100 DV, Perkin Elmer Precisely, USA). All the measurements were conducted in triplicate. Standards for each mineral element were prepared within the concentration range present in the sample. All the conditions for the detection of mineral elements are mentioned in Table 1.

2.10. Microbial analysis

Microbial analyses of control and treated juice samples were performed by using the standard method mentioned in the FDA's Bacteriological Analytical Manual (FDA, 2001). Total plate count was determined by pour plate method. Sterilized distilled water was used to make serial dilutions which were then poured into sterile petri plates after decimal dilution (up to 10^{-5}) of sample. Molten agar (15 mL) was added to each petri dish and the mixing of samples were done five times in directions vertically, clockwise and horizontally, anti-clockwise. The petri dishes were then allowed to set at 25 ± 1 °C for 30 min. The dishes were then shifted to an incubator (GSP-9080 MBE, Shanghai Boxun Industry & Commerce Co., Ltd, China) for 2 days at 32 °C by turning the dishes upside down. Colonies in juice samples were counted (as CFU/mL juice) by multiplying with reciprocal. The results were expressed as log colony-forming units (CFU/mL) of sample.

Pour plate method was used to determine the total yeast and mold counts. Known amount (39 g) of potato dextrose agar (PDA) powder was dissolved in 1000 mL of distilled water to prepare media. To avoid the cross contamination, tartaric acid solution (10:90, w/v) was added in the PDA. All the petri dishes containing PDA were placed in an incubator at 32 ± 1 °C. Then after two days

Table 1
Operating parameters for inductively coupled plasma-optical emission spectrometer.

		Detection wavelengths (λ/nm)	
Nebulization gas flow rate	0.80 L/min	Na	589.592
Auxiliary gas flow rate	0.2 L/min	K	766.490
Plasma gas flow rate	17 L/min	P	213.617
Sample flow rate	1.5 mL/min	Mg	285.213
Operating power	1450 W		
View	Axial		
Interface	Shear gas		
Sample uptake rate	1.0 mL/min		
Spray chamber	Cyclonic		
Nebuliser type	Meinhard		
Nebuliser set up	Instant		
Replicates	3		

the yeast and mold were counted in each petri dish and the results were shown as CFU/mL of juice. All the determinations were carried out in triplicate.

2.11. Statistical analysis

Data obtained in the study were represented as mean value ± standard deviation (SD). Completely Randomized Design (CRD) was used with One-Way ANOVA at a significance level of $P < 0.05$ and significant differences between mean values were determined by LSD pair-wise comparison test. Statistical analyses were determined by using Statistix 9.0 software (Analytical Software, Tallahassee, FL, USA).

3. Results and discussion

3.1. Combined effects of blanching and sonication on chlorogenic acid

Results regarding the combined effects of blanching and sonication on chlorogenic acid of carrot juice are shown in Table 2. Significant ($P < 0.05$) decrease was observed in chlorogenic acid of WB and AB treatments as compared to control samples. Similar results have been reported in previous studies (Ismail, Marjan, & Foong, 2004; Turkmen, Sari, & Velioglu, 2005). The loss of polyphenolic compounds due to blanching can be attributed to the thermal shock, diffusion and leaching of these compounds (Lindley, 1998). However, a significant ($P < 0.05$) increase was observed in chlorogenic acid in all the sonicated, WBS and ABS treatments as compared to control, WB and AB treatments, respectively. Sonication of juice extracted from fresh carrots showed highest level of chlorogenic acid, and ABS treatment also showed the same level of chlorogenic acid as in control. Previously, significant increase in chlorogenic acid of non-thermal clear apple juice treated with ultrahigh pressure homogenization has also been observed (Suárez-Jacobo et al., 2011). Another study also showed significant enhancement of flavanone in high pressure treated orange juice (Plaza et al., 2011). The increase in chlorogenic acid in our study might be attributed to the release of bound form of chlorogenic acid due to disruption of cell wall by the pressure exerted during sonication treatments thus, increase its availability in the carrot juice. Hence, sonication technique in combination with blanching is beneficial as it showed a potential to recover/improve the contents of chlorogenic acid in carrot juice lost during blanching of carrots that is ultimately in favor of human health.

3.2. Combined effects of blanching and sonication on coloring pigments

3.2.1. Total carotenoids

Carotenoids are the antioxidants which play important role in lowering the risk of many diseases (Krinsky & Yeum, 2003; Paolini et al., 2003; Stahl & Sies, 2003). The results regarding the combined effects of blanching and sonication on total carotenoids of carrot juice are depicted in Table 2. Significant improvement in total carotenoids was observed in all the blanched and sonicated treatments such as sonicated, WB, WBS, AB and ABS compared with control untreated juice samples. The highest amount of total carotenoids was observed in the ABS treatment. The color improvement of blanched carrots juice was indirectly due to the improvement in the carotenoids. Blanching could increase the carotene contents which may be due to the increased level of carotenoids (Sharma, Kaur, Sarkar, Singh, & Singh, 2009). The same authors also stated that the beta-carotene increased as the

Table 2
Effects of blanching and sonication on chlorogenic acid, total carotenoids, lycopene and lutein of carrot juice.

Treatments	Chlorogenic acid (µg/mL)	Total carotenoids (µg/mL)	Lycopene (µg/mL)	Lutein (µg/mL)
Control	25.32 ± 0.80[b]	9.52 ± 0.12[d]	0.76 ± 0.03[d]	1.36 ± 0.80[d]
Sonicated	29.46 ± 0.57[a]	9.82 ± 0.15[c]	1.12 ± 0.06[b]	1.62 ± 0.57[c]
WB	21.23 ± 0.62[d]	9.95 ± 0.10[c]	0.95 ± 0.02[c]	1.58 ± 0.62[c]
WBS	23.40 ± 0.71[c]	10.31 ± 0.12[b]	1.43 ± 0.04[a]	1.82 ± 0.71[b]
AB	20.77 ± 0.93[d]	10.25 ± 0.15[b]	1.05 ± 0.03[a]	1.67 ± 0.93[c]
ABS	24.47 ± 0.78[bc]	10.54 ± 0.13[a]	1.36 ± 0.04[a]	1.94 ± 0.78[a]

Values with different letters in the same column (a–d) are significantly different ($P < 0.05$) from each other. WB: water blanched, WBS: water blanched and sonicated, AB: acid blanched, ABS: acid blanched and sonicated.

blanching temperature and pH decreased. Previously, some studies have shown such increase in total carotenoids in orange juice-milk beverage treated with high pressure and orange juice treated with pulse electric field (Barba, Cortés, Esteve, & Frígola, 2012; Cortés, Torregrosa, Esteve, & Frígola, 2006) which are also non-thermal techniques. Similarly, increase in carotenoids was also observed in the orange-carrot juice treated with high intensity pulse electric field (Torregrosa, Cortes, Esteve, & Frigola, 2005). The combination of blanching and sonication is more effective in improving the total carotenoids of carrot juice than their individual effects.

3.2.2. Lycopene

Lycopene is a phytochemical and bright red colored carotene and carotenoid pigment. Results regarding the effects of blanching and sonication on lycopene of carrot juice are mentioned in Table 2. Significant ($P < 0.05$) improvement in lycopene was observed in all the blanched and sonicated treatments, sonicated, WB, WBS, AB and ABS as compared with control fresh untreated juice sample. Results regarding improvement in lycopene due to blanching are in accordance with the observations of Mayer-Miebach and Spieß (2003) who reported 15% improvement in lycopene due to blanching of carrots at 90 °C for 15 min. The improvement in the lycopene due to blanching might be attributed to the reduction in the forces of bonding due to breakdown of cell walls, among lycopene and tissue matrix, thus increasing cis-isomerization by improving lycopene availability (Shi & Maguer, 2000). Improvement in the lycopene bioavailability is attributed to the processing which converts trans-isomers to the more available form of cis-isomers (Garcia & Barrett, 2006). Similarly, increase in bioavailability of lycopene due to sonication might be attributed to the mechanical breakdown of cell wall and disruption of chromoplast membrane due to cavitations produced during sonication and thus making carotenoid more accessible.

3.2.3. Lutein

The results regarding the combined effects of blanching and sonication on the contents of lutein of carrot juice are listed in Table 2. Significant improvements were observed in lutein contents of all the blanched and sonicated treatments such as sonicated, WB, WBS, AB and ABS when compared with control untreated juice samples. The highest amount of lutein was observed in ABS treatment. Previously, increase in lutein contents of carrot slices treated with non-thermal techniques has also been observed which might be attributed to the increase in bioavailability of carotenoids by breaking the chromoplast membranes and cell wall structures (Hussein & el-Tohamy, 1990; Silaste, Alfthan, Aro, Antero Kesäniemi, & Hörkkö, 2007). Similarly, increase in lutein contents additionally, as in non-thermally treated carrot juice due to mechanical disruption, supplied heat in blanching treatment also weakens the forces of bonding between tissues and carotenoids thus increase their concentration and bioavailability. Heat also

converted trans isomers of carotenoids to cis isomers and it was already reported that the cis forms improved the extraction efficiency of carotenoids because of more solubility compared to trans isomeric forms (Kim & Gerber, 1988; Shi & Maguer, 2000). They also proposed the more stability of carotene contents in acid blanched carrots as compared to water blanched carrots.

3.3. Combined effects of blanching and sonication on sucrose, glucose and fructose

The results regarding the combined effects of blanching and sonication on the sugar contents of carrot juice are mentioned in Table 3. Significant ($P < 0.05$) decrease was observed in sucrose, glucose and fructose contents in all the juice samples extracted from blanched carrots WB and AB treatments as compared to control sample while, significant ($P < 0.05$) increase in sonicated, WBS and ABS treatments was observed as compared to control, WB and AB treatments, respectively. Previously, significant decrease in contents of sugars such as sucrose, fructose and glucose has been observed in the blanched beet root, carrots and turnips (Rodrıguez-Sevilla, Villanueva-Suárez, & Redondo-Cuenca, 1999). The results regarding increase in sonicated juice samples are in agreement with many previous studies which proved that sonication increases the extraction of sugars (Fernandes, Gallão, & Rodrigues, 2009; Fonteles et al., 2012; Lieu & Le, 2010). This increase in contents of sugar might be attributed to intracellular sugars that released to the liquid due to cell disruption caused by ultrasonic treatments. Hence, the sonication treatments could improve and recover the sugar level of carrot juice that justifies the commercial implementation of this technique for the processing of carrot juice.

3.4. Combined effects of blanching and sonication on mineral elements

The results regarding the combined effects of blanching and sonication on the Na, K, P and Mg of carrot juice are shown in Table 4. Significant ($P < 0.05$) decrease was observed in Na, K, P and Mg in WB and AB treatments as compared to control sample. Moreover, significant increase in Na and K and decrease in P and Mg was observed in all the sonicated, WBS and ABS treatments as compared to control untreated samples. The results regarding the increasing trend of Na in our study are in agreement with observations of ultrasound treated egg yolk, conversely, the results regarding K, P and Mg are opposite to this study (Sert, Aygun, & Demir, 2011). Further research work is required to understand the exact mechanism of increase or decrease of these elements. Increase in concentration of Na and K in our study is beneficial to the human health that justifies the use of combined treatment of blanching and sonication for the processing of carrot juice.

Table 5
Effects of blanching and sonication on the survival of microorganisms in carrot juice.

Treatments	Total plate count (log CFU/mL)	Yeast and mold counts (log CFU/mL)
Control	4.84 ± 0.14^a	3.90 ± 0.09^a
Sonicated	3.57 ± 0.12^b	3.05 ± 0.15^b
WB	3.64 ± 0.13^b	3.15 ± 0.14^b
WBS	2.97 ± 0.16^c	2.30 ± 0.11^d
AB	3.05 ± 0.14^c	2.74 ± 0.10^c
ABS	2.05 ± 0.09^d	1.94 ± 0.13^e

Values with different letters in the same column (a–e) are significantly different ($P < 0.05$) from each other. WB: water blanched, WBS: water blanched and sonicated, AB: acid blanched, ABS: acid blanched and sonicated.

3.5. Combined effects of blanching and sonication on microbes

Microbial population present in raw fruits and vegetables cause many food borne diseases which adversely affects the human health. Food processing is required to achieve the microbial safety to minimize the consumer's risks. Results regarding the combined effects of blanching and sonication treatments on total plate count, yeast and mold of carrot juice are shown in Table 5 respectively. Significant ($P < 0.05$) reduction was observed in total plate count in all the blanched and sonicated treatments such as sonicated, WB, WBS, AB and ABS as compared with control untreated juice samples. The ABS treatment showed the highest reduction in total plate count. Similarly, we observed significant reduction in yeast and mold in all the treatments. It was also observed that WBS and ABS treatments showed the highest reductions in yeast and mold as compared to other treatments and control untreated juice samples. Similar results have been observed by Buitrago, Barranco, Tapia, Gomez, and López-Malo (2002) who reported significant reduction in micro flora of orange juice as a result of combined treatment of ultra-sonication and blanching. A recent study has also been shown the significant reduction in the microbial population of ultrasound treated apple juice (Abid et al., 2013). The increase in reduction of microbial population of carrot juice was might be due to the biocides by the action of cavitations produce during sonication treatments. In fact, the increase in localized temperature and pressure of product as a result of cavitations and bubble implosions during sonication treatments and the production of shock waves and hydroxyl radicals ultimately cause inactivation of biological species. Therefore, the combined treatment of blanching and sonication shows potential for carrot juice processing as it has resulted in significant reduction in microbial population as well as improvements in other quality parameters.

In the present study, we found that the combined treatments of blanching and sonication significantly improved the coloring pigments, contents of sugar, chlorogenic acid and some mineral elements of carrot juice. Moreover, it also significantly decreased the microbial population of carrot juice. By combining blanching and sonication we could get the benefits of both techniques at the same

Table 3
Effects of blanching and sonication on sucrose, glucose and fructose of carrot juice (g/L).

Treatments	Sucrose	Glucose	Fructose
Control	37.07 ± 0.23^b	13.76 ± 0.22^b	24.56 ± 0.17^b
Sonicated	37.92 ± 0.28^a	14.30 ± 0.20^a	25.25 ± 0.15^a
WB	31.17 ± 0.33^e	8.24 ± 0.24^d	13.03 ± 0.16^e
WBS	33.52 ± 0.22^d	8.82 ± 0.23^c	13.82 ± 0.21^d
AB	34.82 ± 0.38^c	8.29 ± 0.18^d	13.59 ± 0.17^d
ABS	37.01 ± 0.30^b	8.86 ± 0.14^c	14.25 ± 0.15^c

Values with different letters in the same column (a–e) are significantly different ($P < 0.05$) from each other. WB: water blanched, WBS: water blanched and sonicated, AB: acid blanched, ABS: acid blanched and sonicated.

Table 4
Effects of blanching and sonication on mineral elements of carrot juice (mg/L).

Treatments	Na	K	P	Mg
Control	380 ± 0.85^b	1428 ± 0.50^b	213 ± 0.29^a	61 ± 0.20^a
Sonicated	386 ± 0.81^a	1441 ± 0.46^a	210 ± 0.25^b	60 ± 0.21^b
WB	255 ± 0.50^e	1012 ± 0.40^d	206 ± 0.35^c	58 ± 0.15^c
WBS	263 ± 0.76^d	1033 ± 0.41^c	204 ± 0.30^d	57 ± 0.13^d
AB	244 ± 0.57^f	712 ± 0.37^f	176 ± 0.25^e	53 ± 0.10^e
ABS	290 ± 0.75^c	718 ± 0.45^e	173 ± 0.21^f	53 ± 0.12^f

Values with different letters in the same column (a–f) are significantly different ($P < 0.05$) from each other. WB: water blanched, WBS: water blanched and sonicated, AB: acid blanched, ABS: acid blanched and sonicated.

time. On the basis of results obtained, we suggest that the combined treatment of blanching and sonication may successfully be employed on commercial scale for the production of carrot juice with improved quality and safety as well.

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