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Effects of ultrasound treatments on quality of grapefruit juice

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ABSTRACT

Sonication is recognised as a potential technique for improvement in the quality of fruit juices. This study was initiated with the objective of evaluating the effect of sonication treatments on some important quality parameters of grapefruit juice such as physico-chemical (pH, acidity and °Brix), Hunter colour values (L^*, a^* and b^*), cloud value, electrical conductivity, total antioxidant capacity, DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical scavenging activity, ascorbic acid, total phenolics, flavonoids and flavonols. Sonication of grapefruit juice was done in a bath type sonicator at a frequency of 28 kHz by maintaining a constant temperature of 20 °C. Results showed that there was significant improvement in the cloud value, total antioxidant capacity, DPPH free radical scavenging activity, ascorbic acid, total phenolics, flavonoids and flavonols in all the juice samples sonicated for 30, 60 and 90 min but no changes occurred in the pH, acidity and °Brix value as compared to control. Some differences in all the colour values were also observed but overall quality of grapefruit juice was improved, suggesting that sonication technique may successfully be implemented an industrial scale for the processing of grapefruit juice.

1. Introduction

Citrus fruits are very famous due to its high content of vitamin C, which plays an important role in reducing the risk of many diseases originating from oxidative stress. In addition to vitamin C, citrus fruits are also rich in phenolic compounds that are very beneficial to human health due to their antioxidant potential as they scavenge free radicals (Xu et al., 2008). In fact, all the edible varieties of citrus fruits contain citric acid, vitamin C, carotenoids, bioactive compounds, flavonoids, trace elements and dietary fibre (Xu et al., 2008). Among them, grapefruit is a very common variety that can significantly contribute to a healthy human diet. Grapefruit is also an important source of phytochemicals and nutrients, which play a role in the prevention of cancer and chronic diseases (Tirillini, 2000; Tripoli, Guardia, Giammanco, Majo, & Giammanco, 2007; Vanamala et al., 2006). In addition, grapefruit has been reported to have antimicrobial activity due to the presence of antimicrobial compounds including Naringin and naringenin (Cushnie & Lamb, 2005; Tirillini, 2000). In recent years, consumption of processed fruit juice has been increased in the developed countries instead of eating citrus fruits themselves (Ros-Chumillas, Belissario, Iguaz, & Lopez, 2007).

Due to advancement in scientific knowledge consumers are now more conscious about health and diet. They want food not only with extended shelf life but also with improved quality and natural fresh like characteristics. Conventional thermal food processing techniques such as cooling (Hu and Sun, 2000; Wang and Sun, 2001, 2002; Sun and Brosnan, 1999; Sun and Zheng, 2006; Sun and Hu, 2003), freezing (Li and Sun, 2002) and drying (Sun and Woods, 1993, 1994a, 1994b, 1994c, 1997; Sun and Byrne, 1998, Sun, 1999; Delgado and Sun, 2002, Cui, Xu and Sun, 2004) can ensure the safety of food and improve the shelf life but they also cause losses in nutrients (Gómez, Welti-Chanes, & Alzamora, 2011). In order to meet the demands of consumer, researchers are now looking for non-thermal food processing technologies that can not only retain the original properties of food but also improve its nutritional profile. Sonication is a novel technique that has been widely studied for enhancing food processes (Li & Sun, 2002; Sun and Li, 2003; Zheng & Sun, 2006; Delgado, Zheng & Sun, 2009; Kiani, Sun & Zhang, 2013; Tao, García & Sun, 2013), which is also an innovative method for improving the quality of fruit juices (Bhat, Kamaruddin, Min-Tze, & Karim, 2011; Rawson et al., 2011). Also, ultrasound has been acknowledged as a prospective technology to meet the FDA requirement of a 5 log reduction in related microorganisms found in fruit juices (Salleh-Mack & Roberts, 2007). Other benefits of using this technique include reduced processing time, less energy input, and it is an environmental friendly technology (Mason, Riera, Vercet, & Lopez-Bueza, 2005; Tiwari, Muthukumarappan, O'Donnell, & Cullen, 2008a).

Previously, several studies (Bevilacqua, Sinigaglia, & Corbo, 2013; Maia Costa et al., 2013; Gastelum et al., 2012; Char et al., 2010; Char, Guerrero, & Alzamora, 2010; Walkling-Ribeiro et al.,

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2009; Tiwari et al., 2009; Schenk, Guerrero, & Alzamora, 2008) have been conducted on different fruit juices treated with ultrasound in particular kasturi lime juice (Bhat et al., 2011), orange juice (Tiwari et al., 2008a; Valero et al., 2007), strawberry juice (Tiwari, O'Donnell, & Cullen, 2009) and guava juice in combination with carbonation (Cheng, Soh, Liew, & Teh, 2007). To the best of our knowledge, no report is available on the effect of sonication technique on pH, total soluble solids (°Brix), EC, acidity, colour values, cloud value, non-enzymatic browning, total antioxidant capacity, DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical scavenging activity, ascorbic acid, total phenolics, flavonoids and flavonols on the grapefruit juice. Therefore, the current study aims to evaluating the effect of ultrasound on these quality parameters of grapefruit juice.

2. Materials and methods

2.1. Chemicals

DPPH, catechin hydrate, quercetin, gallic acid were obtained from Aladdin Industrial Corporation (Shanghai, China). Ascorbic acid was bought from Accu Standard Inc. (New Heaven, CT 06,513, USA) and sodium hydroxide was purchased from Nanjing Chemical Reagent Co. Ltd., (Nanjing, China). Ethanol and aluminium chloride were attained from Sinopharm Chemical Reagent (Shanghai, China). Folin–Ciocalteu reagent was bought from Guoyao Reagent Co. Ltd., (Shanghai, China). Sodium carbonate was obtained from Guangzhou Chemical Reagent Factory, (Guangzhou, China). Sodium acetate anhydrous and sodium phosphate were gained from Guanghua Chemical Factory (Guangdong, China). Ammonium molybdate was procured from Kaida Huan Chemical Factory (Tianjin, China). Methanol was obtained from Donghua Huan Chemical Factory, (Guangdong, China). Sodium nitrite was procured from Lingfeng Chemical Co. Ltd., (Shanghai, China), sulphuric acid was obtained from Guanzhou Jingkong Reagent Co. Ltd., (Guangzhou, China). All chemicals and reagents used in the study were of analytical (AR) grade.

2.2. Preparation of grapefruit juice

Fresh grapefruits were purchased from a local market (Housetaker Supermarket, Guangzhou, China) to produce fresh juice. The grapefruits were screened and crushed using a domestic juice extractor (JM352, Guangdong Midea Group Co. Ltd., China). The juice was filtered through sterilised double layer muslin cloth to remove the coarse particles and impurities before subjecting to sonication treatments.

2.3. Ultrasound treatments

Sonication treatments were performed directly after fresh juice was extracted. The juice was vortex-mixed and divided into four parts as control (0 min) and as samples to be sonicated for 30, 60 and 90 min. The sonication performed was at 28 kHz frequency (power set at 70%) and temperature of 20 °C using an ultrasonic cleaner with full power of 600 W (SB-600DTY, Ningbo Scientz Biotechnology Co. Ltd., Ningbo, China). All the sonication treatments were carried out in dark to avoid any possible interference of light. Juice samples (control and sonicated) were kept in sterilised and air tight media bottles, and were stored at 4 °C until further analysis.

2.4. Determination of pH, total soluble solids (°Brix) and acidity

To determine the pH of grapefruit juice, a digital pH metre (Mettler FE20, Mettler Toledo, Shanghai, China) was used. Before using, the pH metre was calibrated with commercial buffer solutions of pH 7.0 and pH 4.0.

Total soluble solids were estimated as °Brix with an Abbe refractometer (WYA-2 W, Shanghai Precision & Scientific Instrument Co. Ltd., China). After performing each analysis at room temperature (25 ± 1 °C), the refractometer prism was cleaned thoroughly with distilled water.

For the determination of the acidity of grapefruit juice, the sample of 20 ml was placed into a 250 ml beaker and 80 ml distilled water was added. This solution was then titrated against standardised 0.1 N NaOH (Nanjing Chemicals Reagents, Nanjing, China) to the phenolphthalein end point (pH 8.2 ± 0.1). The volume of NaOH was converted to g citric acid/100 ml of juice (Redd, Hendrix, & Hendrix, 1986) and TA (titratable acidity) was calculated using the following equation:

$$\mathrm{TA}(\%) = (V \times 0.1\ \mathrm{N\ NaOH} \times 0.067 \times 100)/m \quad (1)$$

where V is titre volume of NaOH, and m is mass of grapefruit juice (ml).

2.5. Determination of electrical conductivity and cloud value

The electrical conductivity (EC) of the grapefruit juice was measured by a conductivity metre (DDS-11A, Shanghai Yoke Instrument Co. Ltd., Shanghai, China).

Cloud value of grapefruit juice was determined by following the method outlined by Versteeg, Rombouts, Spaansen, and Pilnik (1980) with some minor changes. Grapefruit juice sample of 5 ml was centrifuged at 3000 rpm for 10 min at 20 °C with the centrifuge (5804R, Eppendorf AG, Hamburg, Germany). Cloud value was determined as the supernatant absorbance at 660 nm using a spectrophotometer (UV 17,800, Shimadzu Suzhou Industrial Mfg. Co. Ltd., Jiangsu, China) with distilled water serving as a blank.

2.6. Determination of NEB and colour value

The non-enzymatic browning of grapefruit juice was determined by the method of Meydav, Saguy, and Kopelman (1977). Grapefruit juice sample was centrifuged at 12,500 g for 10 min with the centrifuge. The supernatant was collected and clarified utilising a 0.45 μm filter. The browning index was determined as the absorbance at 420 nm in the spectrophotometer at room temperature.

The colour of the juice samples were measured using a colorimeter (WSF-J, Shanghai Precision & Scientific Instrument Co. Ltd., China) based on three colour co-ordinates, namely L^*, a^*, b^* at room temperature. The colour values were expressed as L^* (whiteness or brightness/darkness), a^* (redness/greenness) and b^* (yellowness/blueness).

2.7. Determination of ascorbic acid

The ascorbic acid content of the grapefruit juice samples was determined by high performance liquid chromatography-diode array detector (HPLC-DAD) method described by Lee and Coates (1999). The system consisted of a 5 μm Waters Atlantis T3 150 × 4.6 mm column (Waters Co. Milford, Massachusetts, USA), a Waters 600 pump and a Waters 2998 diode array detector (Waters Co. Milford, Massachusetts, USA). The injection volume was 20 μL (filtered through 0.45 μm filters), and the mobile phase (A: water, B: methanol) for elution was 5% B, from 0 to 5 min, then a linear gradient of 5% B to 30% B, from 5 to 10 min, and 30% B to

40% B, from 10 to 45 min, and finally 100% B from 45 to 65 min. The flow rate was set at l ml/min and column temperature was set at 25 °C. Eluate was detected by UV detection at 280 nm with a UV–vis spectrometer (Waters 600 pump and Waters 2998 diode array detector, Waters Co. Milford, Massachusetts, USA). Chromatograms were analysed with ChemStation LC 3D (Rev. A. 10.02). A suitable calibration curve was prepared using standard solution of ascorbic acid and results were expressed as mg 100 ml of grapefruit juice.

2.8. Determination of contents of total phenolics, flavonoids and flavonols

Total phenolic content of grapefruit juice was determined as by spectrophotometric method using Folin–Ciocalteu reagent. This method was proposed by Slinkard and Singleton (1977) with some minor amendments. Briefly 1 ml of 10% Folin–Ciocalteu reagent was added to a 0.5 ml of a known concentration of the sample. The mixture was mixed well and left it for 6 min, and then 2 ml of a 20% sodium carbonate solution was added in the above mixture. The phenols were measured at 760 nm using the spectrophotometer (UV 17,800, Shimadzu Suzhou Industrial Mfg. Co. Ltd, Jiangsu, China) after reacting for 60 min at 30 °C. A calibration curve was prepared using standard solution of gallic acid and the results of total phenols were expressed as μg of gallic acid equivalents (GAE) per gram of sample.

Total flavonoids content were determined by a method described by Dae-Ok, Seung, and Chang (2003) with slight modification. In short, 0.25 ml of the known sample was mixed with 1.25 ml of de-ionised water in a plastic tube and then 75 μl of a 5% sodium nitrite solution was added. After 6 min, 150 μl of a 10% aluminium chloride solution was added and then after 5 min, 0.5 ml of 1 M sodium hydroxide was added. The final volume was made to 2.5 ml with distilled water and mixed well. The absorbance was measured at 415 nm by using a spectrophotometer. The results were expressed as μg of (+)-catechin equivalents per gram of sample.

Total flavonols of grapefruit juice samples were measured using the method of Kumaran and Karunakaran (2007). A known aliquot of sample (2.0 ml) or standard was mixed with 2.0 ml of 2% $AlCl_3$ solution, then 3.0 ml (50 g/l) sodium acetate solution was added. The mixture was placed at 20 °C for 150 min. The absorption was measured at 440 nm by using the spectrophotometer and the results were described as μg of quercetin equivalents per gram of sample.

2.9. Determination of DPPH free radical scavenging activity

DPPH free radical scavenging activity of the grapefruit juice was measured using a method explained by Yi, Yu, Lianga, and Zeng (2008) with some minor alterations. To a known aliquot (2 ml) of the juice, 2 ml of DPPH solution (0.2 mM in ethanolic solution) was added, followed by incubation in dark for 30 min at room temperature (25 ± 1 °C). The same procedure was conducted for blank but ethanol was used instead of the sample solution. The decrease in the absorbance (due to the proton donating activity) was measured at 517 nm using the spectrophotometer. The DPPH radical scavenging activity was calculated as:

$$\text{DPPH radical scavenging activity}(\%) = [A_0 - A_1/A_0] \times 100 \quad (2)$$

where, A_0 is the absorbance of the control, and A_1 is the absorbance of the extracts.

2.10. Determination of antioxidant capacity

Antioxidant capacity of the grapefruit juice was measured by the method described by Prieto, Pineda, and Aguilar (1999). A known aliquot of the juice sample was taken in a vial (0.4 ml, 250 μg/ml in methanol) and 4 ml of reagent solution containing 28 mM sodium phosphate, 4 mM ammonium molybdate and 0.6 M sulphuric acid were added in it. Furthermore, this mixture was incubated in a water bath for 90 min at 95 °C. The blank solution contained 4 ml of the reagent solution and 0.4 ml of methanol. After cooling to room temperature (25 ± 1 °C), the absorbance of this mixture was measured at 695 nm using the spectrophotometer against the blank. A suitable calibration curve was prepared using standard solution of ascorbic acid (100–400 μg/ml) and antioxidant activity was expressed relative to that of ascorbic acid.

2.11. Statistical analysis

All the measurements were performed in triplicate. Data obtained were represented as mean value ± standard deviation (SD). Completely randomised design (CRD) was conducted with one-way ANOVA at a significance level of $P < 0.05$, significant differences between mean values were determined by LSD (least significant differences) pair-wise comparison test. Statistical analyses were determined using Statistix 9.0 software (Analytical Software, Tallahassee, FL, USA).

3. Results and discussion

3.1. Effect of sonication on pH, acidity, °Brix and EC

Results regarding the effect of sonication treatments on pH, titratable acidity and °Brix are shown in Table 1. Sonication did not induce any change in the pH, titratable acidity and °Brix of grapefruit juice rather these parameters remained stable even after treatment for 60 and 90 min. Similar results regarding pH and acidity were observed in tomato and orange juices treated with ultrasounds (Adekunte, Tiwari, Cullen, Scannell, & O'Donnell, 2010; Tiwari, Muthukumarappan, O'Donnell, & Cullen, 2008b). No significant changes in pH, acidity and °Brix were also observed in sonicated apple juice (Zhang, Zhang, Chen, Zhang & Hua, 2012).

Electrical conductivity of liquid foods is due to the nutrients like vitamins, minerals, fatty acids and proteins (Martín, Zhang, Castro, Barbosa-Cánovas, & Swanson, 1994). Results regarding the effect of sonication treatments on the EC of grapefruit juice are also listed in Table 1, indicating significant increase in EC for sonicated grapefruit juice, with samples treated for 90 min exhibiting the highest value. This increase in EC of grapefruit juice might be attributed to the increase in minerals and vitamin contents due to sonication treatments.

3.2. Effect of sonication on cloud value

Cloud is a desirable quality parameter in fruit juices and it is related to the particles composed of cellulose, hemicelluloses, protein, lipids, pectin and some other minor components (Baker & Cameron, 1999). It improves the flavour and colour of fruit juices. Results regarding the effect of sonication treatments on the cloud value of grapefruit juice are shown the Table 1. Significant increase in cloud value of all the sonicated juice samples was observed when compared with control. This increase might be attributed to that sonication treatments break the larger molecules into the smaller ones due to high pressure gradient exerted by cavitation and ultimately homogenise the juice properly. The breakdown of larger molecules enhances the number of suspended particles,

Table 1
Effect of sonication on °Brix, pH, titratable acidity, cloud value, EC, colour and non-enzymatic browning in grapefruit juice ($n = 3$).

Samples	pH	TA (%)	TSS (°Brix)	Cloud value	EC (ms/cm)	colour attributes			NEB
						L^*	a^*	b^*	
Control	4.91 ± 0.01^a	0.16 ± 0.01^a	9.60 ± 0.20^a	0.42 ± 0.003^d	3.01 ± 0.02^c	7.58 ± 0.03^a	5.50 ± 0.02^a	−11.84 ± 0.05^c	0.221 ± 0.007^c
US30	4.91 ± 0.01^a	0.16 ± 0.01^a	9.53 ± 0.10^a	1.04 ± 0.013^c	3.16 ± 0.06^b	7.24 ± 0.05^b	4.55 ± 0.05^c	−9.29 ± 0.08^a	0.225 ± 0.004^c
US60	4.90 ± 0.01^a	0.16 ± 0.01^a	9.50 ± 0.10^a	1.09 ± 0.003^b	3.22 ± 0.04^{ab}	7.05 ± 0.08^c	4.88 ± 0.07^b	−9.67 ± 0.06^a	0.299 ± 0.005^b
US90	4.90 ± 0.01^a	0.16 ± 0.01^a	9.50 ± 0.23^a	1.11 ± 0.003^a	3.26 ± 0.03^a	6.95 ± 0.03^d	4.56 ± 0.04^c	−12.11 ± 0.03^d	0.315 ± 0.005^a

Values with different letters in the same column (a–d) are significantly different ($P < 0.05$) from each other. US30: sonication treatment for 30 min; US60: sonication treatment for 60 min; US90: sonication treatment for 90 min; TA: titratable acidity; TSS: total soluble solids; EC: electrical conductivity; NEB: non-enzymatic browning.

Table 2
Effect of sonication on ascorbic acid, total phenols, flavonoids and flavonols in grapefruit juice ($n = 3$).

Sample	Ascorbic acid (mg/100 ml)	Total phenolics (gallic acid equivalent μg/g)	Total flavonoids (catechin equivalent μg/g)	Total flavonols (quercetin equivalent μg/g)	Percentage inhibition (DPPH radical)	Antioxidant capacity (ascorbic acid equivalent μg/g)
Control	27.83 ± 0.03^d	757.96 ± 0.04^d	462.27 ± 0.08^d	2.70 ± 0.04^c	32.80 ± 0.11^d	276.72 ± 0.04^d
US30	31.81 ± 0.04^c	769.93 ± 0.07^c	485.00 ± 0.04^c	2.83 ± 0.03^b	38.65 ± 0.15^c	296.72 ± 0.03^c
US60	35.40 ± 0.08^b	814.30 ± 0.06^b	598.64 ± 0.06^b	2.92 ± 0.07^a	41.74 ± 0.24^b	303.62 ± 0.05^c
US90	35.75 ± 0.07^a	826.27 ± 0.08^a	603.18 ± 0.03^a	2.94 ± 0.02^a	42.78 ± 0.35^a	308.89 ± 0.10^a

Values with different letters in the same column (a–d) are significantly different ($P < 0.05$) from each other. US30: sonication treatment for 30 min; US60: sonication treatment for 60 min; US90: sonication treatment for 90 min.

lowers the distance among particles by the enlargement of surface area, and thus improves the clouds in the juice (Rao, 1999). Therefore sonication technique could improve the consistency of grapefruit juice.

3.3. Effect of sonication on non-enzymatic browning (NEB) and colour attributes

Browning is an important parameter on which the quality of stored and processed food is based. In citrus fruit juices mostly, the degradation of ascorbic acid may cause non-enzymatic browning. Results regarding effect of sonication treatments on NEB for grapefruit juice are depicted in Table 1. Significant increase in NEB for all sonicated juice samples was observed as compared to control. This increase in NEB might be attributed to the breakdown of colouring pigments caused by sonication treatments. The observation was in agreement with that of sonicated apple cider (Ugarte-Romero, Feng, Martin, Cadwallader, & Robinson, 2006).

Colour is a visual indicator to judge the quality of fruit juices and plays an important role in consumer satisfaction. Results regarding the effect of sonication treatments on colour values of grapefruit juice are given in Table 1. It can be observed that significant differences in all the colour values of grapefruit juice treated with sonication for 30, 60 and 90 min existed as compared control. The sample treated for 90 min showed the lowest colour values for lightness (L^*), redness (a^*) and yellowness (b^*) while the highest values for L^* and a^* were observed in the control while b^* was the highest in the sample treated for 60 min. Similar trend of decreasing colour values was previously shown in guava juice treated with sonication and carbonation (Cheng et al., 2007). Although sonication treatments induced changes in all the colour values of grapefruit juice, these changes were not easily seen by the naked eyes. Therefore, it is suggested that the sonication technique might be employed for the processing of grapefruit juice.

3.4. Effect of sonication on ascorbic acid

Ascorbic acid contributes substantially towards prevention of many cardiovascular and cancer diseases (Marín, Martinez, Uribesalgo, Castillo, & Frutos, 2002). Heat and oxygen are the main responsible factors for its degradation. Results regarding the effect of sonication treatments on the contents of vitamin C of grapefruit juice are listed in Table 2, showing significant increase in vitamin C in all the sonicated juice samples as compared to control. Previous study conducted on sonicated kasturi lime juice also showed the same increase regarding vitamin C (Bhat et al., 2011). This increase in vitamin C could be ascribed to the removal of entrapped oxygen due to cavitation (Cheng et al., 2007). Previous studies also showed degradation of vitamin C in sonicated fruit juice (Adekunte, Tiwari, Cullen, Scannell, & O'Donnell, 2010) but in our study the increase in vitamin C as a result of sonication treatments of grapefruit juice is highly beneficial to the human health.

3.5. Effect of sonication on total phenols, total flavonoids and total flavonols

Phenolic compounds are very important and beneficial to human health as they play a significant role in controlling the risk of many physiological and degenerative diseases in the human body. Results regarding the effect of sonication treatments on the total phenolic compounds of grapefruit juice are shown in Table 2. It can be seen that there was significant increase in total phenols in all the sonicated juice samples as compared to control. Previous study conducted on sonicated kasturi lime juice also showed similar trend of increase in total phenolic content (Bhat et al., 2011). This increase might be attributed to the release of bound form of phenolic contents due to breakage of cell wall by the cavitation pressure exerted on it during sonication. It could also be due to the addition of hydroxyl group produced by sonication, to the aromatic ring of phenolic compounds.

Flavonoids are also very important and beneficial polyphenolic contents that lower the risk of cancer and cardiovascular diseases (Hertog, Hollman, & Katan, 1992). Results regarding the effect of sonication treatments on the flavonoids and flavonols content of grapefruit juice are also listed in Table 2, showing significant increase in total flavonoids and flavonols in all the sonicated juice samples as compared with control. Significant increase in flava-

none has already been observed in orange juice treated with high pressure (Plaza et al., 2011).

3.6. Effect of sonication on DPPH free radical scavenging activity and antioxidant capacity

In fruits and vegetables, phenolic compounds and vitamin C especially in citrus fruits are the major components responsible for DPPH free radical scavenging activity and antioxidant capacity. These compounds have potential to scavenge the free radicals that cause damage to the body and also reduce the risk of many diseases originating from the oxidative stress. Results regarding the effect of sonication treatments on DPPH free radical scavenging activity and antioxidant capacity of grapefruit juice are shown in Table 2. As indicated in Table 2, significant increase exists in both DPPH free radical scavenging activity and total antioxidant capacity in all sonicated juice samples which is in agreement with the observations of sonicated kasturi lime juice (Bhat et al., 2011). This increase might be attributed to the increased amount of phenolic compound as a result of cavitation produced during sonication.

Phenolic compounds are one of the main contributors in antioxidant activity in fruit juices and polyphenolic compounds are commonly found in both edible and inedible plants which have been reported to have multiple biological effects and antioxidant activities (Van Acker et al., 1996; Kähkönen et al., 1999). Previous studies shown that there is a positive relation between total phenolic content and antioxidant activity in many plant species (Duh, Tu, & Yen, 1999; Gulcin, Kufrevioglu, Oktay, & Buyukokuroglu, 2004) and has been widely studied in different foodstuffs such as vegetables and fruit (Jayaprakasha, Girennavar, & Patil, 2008; Kedage, Tilak, Dixit, Devasagayam, & Mhatre, 2007; Kiselova et al., 2006; Klimczak, Malecka, Szlachta, & Gliszczynska-Swiglo, 2007). Significant increase in the antioxidant activity is related to presence of high concentration of total polyphenol content in vegetables and fruits.

4. Conclusions

In this study, improvement was shown in selected parameters of grapefruit juice treated with ultrasound. No significant differences in pH, acidity and °Brix, but significant increases in EC sonicated sample were observed after ultrasound treatments. Small differences in colour were also observed but overall quality of grapefruit juice was improved. Further research is needed, to optimise sonication treatments by changing the time, frequency and temperature, and to evaluate the effects of ultrasound treatments on individual polyphenolic compounds and mineral contents of grapefruit juice. The current study implied that ultrasound as a simple and economical technique could be used to enhance extraction yield and nutritional quality of grapefruit juice, but further investigation is still needed to confirm this.

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