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Effect of sonication on soursop juice quality

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ABSTRACT

Soursop juice was submitted to sonication at amplitude levels ranging from 20 to 100 % of the total input power (500 W) at constant frequency of 19 kHz for different times (2–10 min). Response surface methodology based on a central composite design was applied to investigate the effect of ultrasound on polyphenol oxidase (PPO) residual activity, temperature increase, color, ascorbic acid and phenolic compounds. After processing, the PPO activity in the juice was reduced and color changes were subtle. A good retention of phenolic compounds was obtained at higher intensity. Ascorbic acid content was found to be higher in most of the samples treated. The higher the ultrasound intensity and the juice exposure time, the higher its final temperature. An optimum set was chosen and the final product was submitted to a sensorial test. The sonicated sample had a good acceptance. The technology could be suitable as an alternative to thermal and other treatments that results in quality loss.

1. Introduction

Soursop (*Annona muricata*) from the Annonaceae family is an important tropical fruit that contributes to the economic growth of some tropical countries, namely, tropical America, Australia, Africa and Malaysia (Shashirekha, Baskaran, Rao, Vijayalakshmi, & Rajarathnam, 2008). It is prized for its very pleasant, sub-acid, aromatic and juicy flesh, excellent for making drinks and sherbets. The soursop pulp is widely used for manufacturing various juice blends, nectars, syrups, shakes, jams, jellies, preserves and ice creams; it is also a raw material for powders, fruit bars and flakes (Telis-Romero, Beristain, Gabas, & Telis, 2007).

Over the past few years, an increase on food demand either in terms of quantity or quality is observed, imposing modifications in the processing techniques (Pingret, Fabiano-Tixier, & Chemat, 2013). Thermal treatment is the most common and widely employed pasteurization and sterilization technique for the inactivation of microorganisms and enzymes in the food industry (Adekunte, Tiwari, Cullen, Scannell, & O'Donnell, 2010). Consumer demand is growing for food products based on natural, health-promoting plants, such as those of fresh fruit juices that are microbially safe with improved quality and extendable shelf life. To date, various innovative technologies, such as radiation processing, hydrothermal treatments, osmotic dehydration, pulsed electric field applications and others have been explored for shelf life improvement and for preservation of nutritional and organoleptic qualities of fresh fruits or their products. Among these technologies exists sonication (ultrasound) treatment, which is an emerging technology that is considered to be inexpensive, simple, reliable, environmentally friendly and highly effective in achieving microbial decontamination (Tiwari, O'Donnell, & Cullen, 2009).

Ultrasound is a rapidly growing field of research, which finds increasing use in the food industry (Zheng & Sun, 2006). Ultrasound waves result from the conversion of electrical energy into mechanical one by means of piezoelectric materials. When the ultrasonic energy propagates in the liquid, cavitation bubbles are formed due to pressure changes. These bubbles collapse violently in subsequent cycles of compression as the sound wave propagates, resulting into regions of high temperature and pressure. The energy transmitted to the food through ultrasound processing can be expressed as power ultrasound (W), ultrasound intensity (W/cm^2), acoustic energy density (W/mL), or cavitational intensity (O'Donnell, Tiwari, Bourke, & Cullen, 2010).

Various research groups have demonstrated the inactivation of pathogenic and spoilage microorganisms and enzymes (Valdramidis, Cullen, Tiwari, & O'Donnell, 2010). These inactivations have been reported as dependent on the nature of the enzyme; the process variables (ultrasound power intensity,

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ultrasound frequency, temperature or pressure); the characteristics of the medium (viscosity, food matrix composition) as well as on the type of connection and chemical reactions that they establish with other molecules (O'Donnell et al., 2010).

Polyphenol oxidase (PPO) is a copper-containing enzyme that causes enzymatic browning in fresh fruits and vegetables products such as juices. Enzymatic browning is one of the biggest problems faced during the processing of fruits and vegetables (Yemenicioglu & Cemeroglu, 2003). This enzyme is usually inactivated by thermal treatments, which demand large amount of energy, besides imparting several quality losses (Pereira & Vicente, 2010).

Previously, several studies have been conducted on different fruit juices treated with ultrasound, in particular kasturi lime juice (Bhat, Kamaruddin, Min-Tze, & Karim, 2011), orange juice (Tiwari, Muthukumarappan, O'Donnell, & Cullen, 2008), strawberry juice (Tiwari et al., 2009), watermelon juice (Rawson et al., 2011), grapefruit juice (Aadil, Zeng, Han, & Sun, 2013) and guava juice in combination with carbonation (Cheng, Soh, Liew, & The, 2007). To the best of our knowledge, few are addressed to enzyme inactivation and the effects of sonication on soursop juice quality parameters have not been reported elsewhere. Therefore, the objective of this work was to investigate the impact of high-intensity ultrasound processing conditions (time and intensity) on polyphenol oxidase activity, phenolic compounds, ascorbic acid content, color values and temperature, using response surface analysis. An optimum ultrasound operation condition was chosen and a sensory analysis was performed.

2. Material and methods

2.1. Juice preparation

Soursop (*A. muricata* L.) was prepared from frozen fruit pulps obtained from local industry (Recife, Brazil) without addition of preservatives and non-pasteurized. The pulp was diluted in distilled water (ratio 1:1) and the juice was stored at 4 °C prior to processing.

2.2. Sonication treatment

A 500 W ultrasound processor (Unique® DES500, Brazil) with a 1.3 cm diameter probe tip was used for juice sonication. Samples were processed at a constant ultrasound frequency of 19 kHz. Soursop juice samples (150 mL) were placed in a 250 mL glass beaker. The ultrasound probe was submerged to a depth of 25 mm in the sample.

The energy input was controlled by setting the amplitude of the sonicator probe. Extrinsic parameters of amplitude and time were varied according to an experimental design. The power levels were adjusted to 20%, 30%, 60%, 90% and 100% of total input power (500 W), which corresponded to intensities of 75, 118, 224, 330 and 373 W/cm^2, respectively. Due to the heat generated by power ultrasound, short processing times (2–10 min) were applied (Tiwari et al., 2009) and the initial and final temperature were recorded for all samples. The sample's temperature was determined using a digital thermometer. The procedure consisted of immersing the thermometer into the juice immediately after sonication.

2.3. Experimental design

A central composite rotatable design (Khuri & Cornell, 1996) was used for designing the experiments for sonication of soursop juice using two factors: power intensity and processing time. Five levels of each variable were chosen for study, including the center point and two axial points. A total of 11 combinations were performed, including three replications of the center point (Table 1).

It was assumed that a mathematical function, φ, exists for the response variable Y (polyphenol oxidase activity, phenolic compounds, ascorbic acid content, color values and temperature increase), in terms of two independent process variables (Khuri & Cornell, 1996), power intensity (i) and processing time (t):

$$Y = \varphi\left(i,t\right) = \beta_o + \beta_1 i + \beta_2 t + \beta_{11} i^2 + \beta_{22} t^2 + \beta_{12} it \quad (1)$$

The Statistica 7.0 package was used in order to obtain the regression coefficients, analysis of variance, test of lack of fit and the generation of three dimensional graphs.

2.4. Polyphenol oxidase assay

For polyphenol oxidase (PPO, EC 1.14.18.1) determination, the enzyme extraction and PPO activity were done according to the methodology described by Wissemann and Lee (1980). For the extraction, 20 mL of soursop juice was mixed with the same volume (20 mL) of potassium phosphate buffer (0.05 mol/L pH 7.0) containing 1 g/100 mL of polyvinylpyrrolidone (PVP) and KCl (0.1 mol/L). The mixture was centrifuged twice (10 min each time) in an Eppendorf®5403 centrifuge (Germany) (15,557 × *g* at 4 °C). The supernatant was used as the enzyme source. The reaction mixture contained 0.3 mL of enzyme extract and 1.85 mL of a potassium phosphate buffer solution (0.1 mol/L pH 6.0) containing catechol (0.1 mol/L) and KCl (0.1 mol/L). The reaction mixture was incubated at 30 °C for 30 min. The reaction was interrupted with the addition of 0.8 mL of perchloric acid 2 mol/L. One unit of enzyme activity (1 UEA) was defined as the amount of enzyme that causes a change of 0.001 in the absorbance (395 nm) per minute. All measurements were carried in triplicate.

The residual enzyme activities (RA) of PPO after sonication were calculated according to Eq. (2). The value of enzymatic activity found in the fresh juice (A_o) corresponded to 100%. The residual enzymatic activity found after juice sonication (A_s) was calculated as the percentage (%) ratio of the processed samples to the fresh juice.

$$\text{RA}\ \left(\%\right) = \frac{A_s}{A_o} \cdot 100 \quad (2)$$

2.5. Determination of total phenolic compounds

Total phenolic content was determined using the Folin–Ciocalteau reagent according to the method of Singleton, Orthofer, and Lamuela (1999). The reaction mixture contained: 0.5 mL of phenolic extract, 2.5 mL Folin–Ciocalteu (Sigma–Aldrich, Germany) reagent and 2 mL of sodium carbonate 4 g/100 g. The mixture was then left in the dark for 2 h at room temperature. The absorbance of the sample was measured at 760 nm using aqueous Gallic acid (5–100 μg/mL) as a standard. Results were expressed as μg of Gallic acid equivalent per 100 mL of sample. All measurements were carried in triplicate.

2.6. Determination of ascorbic acid

Ascorbic acid content was determined according to Strohecker and Henning (1967). Samples of 15 mL each were diluted to 100 mL with 0.5 g/100 mL oxalic acid at 4 °C in volumetric flask. An aliquot of 5 mL filtrate was titrated with 2,6-dichlorophenol indophenol (DCPIP) indicator to the end point. Ascorbic acid content was calculated as mg ascorbic acid per 100 mL sample juice. All measurements were carried in triplicate.

Table 1
Experimental design and responses on characteristics of soursop juice.

Treatment	Ultrasonic intensity (W/cm^2)	Time (min)	PPO residual activity (%)	ΔT (°C)	Phenolic content (μg/100 mL)	Ascorbic acid content (mg/100 mL)	L^*	a^*	b^*	TCD
Control	–	–	–	–	34.63 ± 1.21	8.92 ± 0.60	74.57 ± 0.30	−0.19 ± 0.02	1.76 ± 0.02	–
1	118	3	92.57 ± 0.44	4.4	28.13 ± 0.10	8.92 ± 0.00	75.74 ± 0.05	−0.28 ± 0.01	1.69 ± 0.05	0.57
2	330	3	91.99 ± 0.17	35.0	23.60 ± 0.94	7.73 ± 0.00	77.76 ± 0.27	−0.14 ± 0.02	1.57 ± 0.02	2.58
3	118	9	92.42 ± 0.90	1.0	25.45 ± 0.35	9.51 ± 0.31	75.02 ± 0.62	−0.30 ± 0.02	1.43 ± 0.02	0.40
4	330	9	85.27 ± 1.71	43.9	24.76 ± 0.20	7.73 ± 0.05	75.80 ± 0.23	−0.50 ± 0.01	0.06 ± 0.01	1.84
5	224	6	94.72 ± 0.83	32.2	24.72 ± 0.35	10.70 ± 0.09	74.32 ± 0.15	−0.68 ± 0.01	0.59 ± 0.05	1.29
6	224	6	95.42 ± 0.02	35.1	28.15 ± 0.07	10.70 ± 0.11	74.66 ± 0.28	−0.64 ± 0.01	0.61 ± 0.03	1.24
7	224	6	95.28 ± 0.91	36.5	28.87 ± 1.06	10.11 ± 0.63	74.80 ± 0.10	−0.64 ± 0.02	0.60 ± 0.01	1.27
8	75	6	90.49 ± 0.23	4.1	33.81 ± 0.60	5.95 ± 0.51	75.62 ± 0.10	−0.45 ± 0.02	1.50 ± 0.02	0.57
9	373	6	85.84 ± 1.02	30.5	31.66 ± 0.71	7.14 ± 0.37	73.56 ± 0.03	−0.83 ± 0.02	−0.57 ± 0.04	2.51
10	224	2	98.58 ± 0.08	3.6	31.20 ± 0.47	8.92 ± 0.08	75.65 ± 0.28	−0.51 ± 0.02	1.05 ± 0.01	0.92
11	224	10	89.13 ± 0.33	40.6	27.35 ± 1.52	8.83 ± 0.013	74.59 ± 0.06	−0.60 ± 0.02	−0.08 ± 0.01	1.96

2.7. Color

The color of the soursop juice was determined using a Minolta CR400 colorimeter (Japan). The colorimeter (65°/0° geometry, D25 optical sensor, 10° observer) was calibrated prior to taking any reading. The reflectance instruments determined three color parameters: L^* (whiteness or brightness), a^* (redness/greenness), and b^* (yellowness/blueness). Numerical values of L^*, a^* and b^* were converted into TCD (total color difference), which indicates the magnitude of color change after treatment, using Eq. (3). The reference value for TCD was the non-sonicated juice. Color measurements were taken in quintuplicate.

$$\mathrm{TCD} = \sqrt{\left(L^* - L_o^*\right)^2 + \left(a^* - a_o^*\right)^2 + \left(b^* - b_o^*\right)^2} \quad (3)$$

The sub-indice o in Eq. (3) mean the control sample (non-treated).

2.8. Sensory analysis

Soursop juice with and without ultrasonic treatment was evaluated by 61 non-trained panelists for appearance (overall liking), texture (viscosity), taste and aroma on a 9-point hedonic scale (1 = "disliked extremely"; 9 = "liked extremely"). Prior to sensory evaluation juice samples were refrigerated, randomly coded with three-digit numbers and their order of presentation was completely randomized for each panelist. Partitioned booths with fluorescent lighting were used for evaluation and these were located in Dietetic Technics Laboratory of the Department of Nutrition, Federal University of Pernambuco (Recife, Brazil).

A two-way analysis of variance (ANOVA) was used to test the effects of processing pretreatments on the sensory attributes of soursop juice.

3. Results and discussion

3.1. Polyphenol oxidase activity

Polyphenol oxidase (PPO) is frequently involved in multiple deteriorative changes, such as enzymatic browning, with consequent loss of sensorial and nutritional properties of fruit and vegetables (Oms-Oliu, Odriozola-Serrano, Soliva-Fortuny, & Martín-Belloso, 2008). Polyphenol oxidase activity of fresh soursop juice and the responses of each run of the experimental design are presented in Table 1. The obtained codified equation (Eq. (4)) was tested for adequacy and fitness by analysis of variance (ANOVA). The analysis of variance for the model as fitted showed significance ($p \leq 0.05$) and explained 96% of the variability in the enzyme activity. Therefore, the model as fitted provide an approximation to the true system.

$$\mathrm{PPO_{RA}} = 95.14 - 1.79i - 2.53t - 3.62i^2 - 0.75t^2 - 1.64it \quad (4)$$

The generated surface is presented in Fig. 1. Results indicated that polyphenol oxidase enzyme activity reduction was observed in the whole experimental domain, independent of the processing time and power intensity used. However, lower values of PPO residual activity were obtained when higher processing time (>8 min) and power intensity (>330 W/cm^2) were applied.

Inactivation of monomeric enzymes generally involves either defragmentation of the enzyme or formation-into aggregates, whereas polymeric enzymes tend to fragment into monomeric subunits, during ultrasonication. Inactivation of enzymes by ultrasound is primarily attributed to cavitation phenomenon. Indeed, the cavitation effects generated by bubble collapse (mechanical, thermal, chemical) may be sufficient to cause irreversible destruction and deactivation of enzymes (Mawson, Gamage, Terefe, & Knoerzer, 2011). In addition, the extreme agitation created by microstreaming could disrupt Van der Waals interactions and hydrogen bonds in the polypeptide, causing protein denaturation (Tian, Wan, Wang, & Kang, 2004).

Generally, ultrasonication in combination with other treatments is more effective in enhancing the enzyme inactivation efficacy (Chandrapala, Oliver, Kentish, & Ashokkumar, 2012). A synergistic effect of heat and pressure with ultrasound has been reported for the

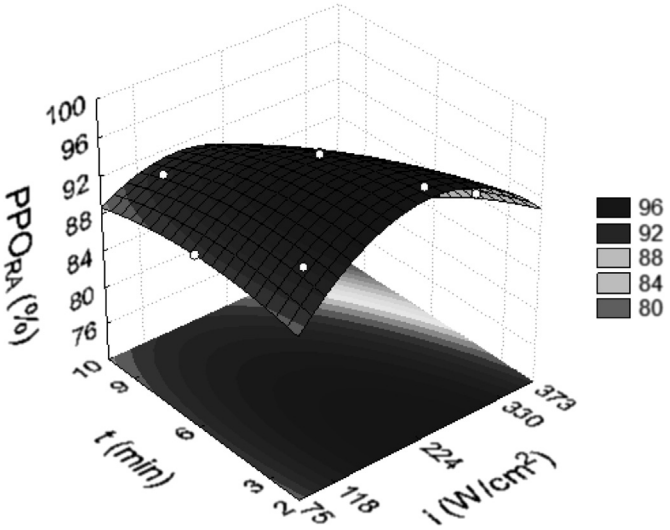

Fig. 1. Response surfaces for soursop juice PPO residual activity (PPO_{ra}) as a function of power intensity (i) and processing time (t).

inactivation of PPO in model buffer systems (López, Sala, de la Fuente, Raso, & Burgos, 1994). They reported a linear decrease in log D values for an increase in ultrasound amplitude level. In this study, reduction of PPO activity was observed without the use of chemical additives or external heating. In addition, as observed by Fonteles et al. (2012) for melon juice, the activity of PPO of the control sample was considered low compared to other fruits, such as apple.

3.2. Temperature increase

Juice temperature after sonication confirmed the effect of the cavitation phenomenon (collapse and implosion of bubbles), which led to the temperature increase (Table 1).

The ultrasound intensity and processing time significantly affected the final temperature. All regression coefficients were significant ($p \leq 0.05$), except the interaction between the variables, and the obtained codified equation (Eq. (5)) was tested for adequacy and fitness by analysis of variance (ANOVA). The regression model is significant at the considered confidence level since a satisfactory correlation coefficient was obtained and the F-value was greater than the F listed value.

$$\Delta T = 34.60 + 13.88i + 7.23t - 8.33i^2 - 5.92t^2 \quad (5)$$

The response surface graph (Fig. 2) shows that the increase of processing time and power intensity caused significant increase of the juice temperature (ΔT). As observed before, when increasing these variables, lower PPO residual activity values were obtained. Thus, the energy liberated by ultrasound may have caused a synergistic effect on enzyme denaturation, as observed by Fonteles et al. (2012) for melon juice.

Temperature increase up to 60 °C was reached combining maximum intensity (373 W/cm^2) and time (10 min) (Fig. 2). The PPO residual activity obtained keeping the juice at 60 °C for 10 min was 91.80%. Thus, the higher temperature recorded after juice sonication was unable to denature PPO, attesting that inactivation shown in Fig. 1 was mainly due to the sonication.

3.3. Total phenolic compounds

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 (Aadil et al., 2013). Results regarding the effects of ultrasound intensity and processing time on soursop juice phenolic compounds were not statistically significant. Thus, the response surface methodology was not applied to evaluate the experimental data.

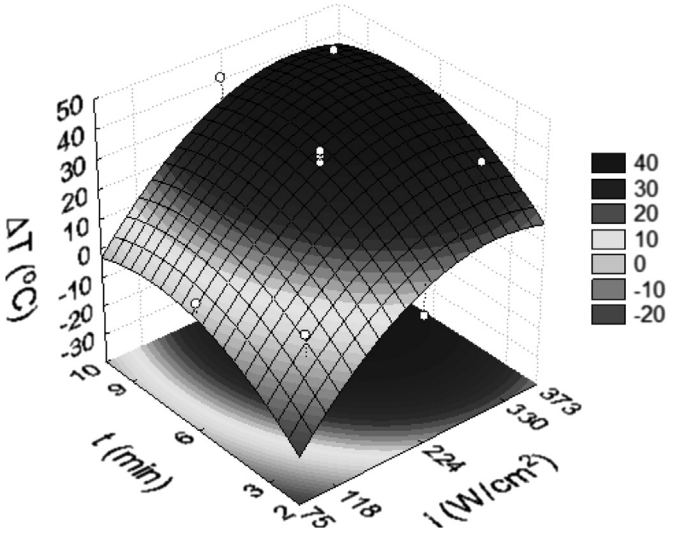

Fig. 2. Response surfaces for soursop juice temperature increase (ΔT) as a function of power intensity (i) and processing time (t).

It can be observed from the results presented in Table 1 a reduction in the levels of these compounds. The highest phenolic retention was achieved in assay 8, which used intermediate processing time and low ultrasound intensity. However, when the higher ultrasound intensity was used, maintaining the same intermediate processing time (assay 9), it was observed one of the highest retention of phenolic compounds (91.4%), even with an increase in the liquid temperature much higher for this assay. A similar trend was observed for blackberry juice, when during sonication a decrease of 5% was observed at maximum treatment conditions of 100% amplitude for 10 min (Tiwari et al., 2009). However, for the rest of the soursop juice assays, increasing ultrasonic intensity keeping process duration constant (for instance, comparing assays 1 and 2, or 3 and 4, or 10 and 11) resulted in lower phenolic content and in an increase in sample temperature. Similar behavior was observed when the ultrasound intensity is constant and time varies (comparing assays 1 and 3, 10 and 11, 10 and 5 or 6 or 7).

The reduction in phenolic compounds might be attributed to the formation of free radicals, which may have affected these compounds of the soursop juice since –OH radicals formed during cavitation can affect the bioactive compounds such as phenolics (Wan et al., 2005). Sadilova, Carle, and Stintzing (2007) observed that hydroxyl radicals produced by cavitation could be involved in the degradation of anthocyanins by opening of rings and formation of chalcone. Hrazdina (1971) postulated opening of the pyrylium ring and chalcone formation as a first degradation step. Furthermore, Adams and Ongley (1973) proposed hydrolysis of the glycosidic moiety and aglycon formation as the initial reaction.

Abid et al. (2013), when studying the effect of ultrasound on different quality parameters of apple juice, reported that enhanced disruptions of cell wall due to cavitation as a result of rapid change in pressures of the liquid by shear forces exerted during sonication which might lead to the release of some chemically bound phenolic phytonutrients and ultimately increased their availability in the juice. Creation of hydroxyl radicals by bubble implosion during sonication to the aromatic ring of phenolic compounds might also be a cause of improvement in the apple juice. Ashokkumar et al. (2008) observed that increase in antioxidant capacity of phenolic compounds might be attributed to the addition of second hydroxyl group in the *ortho*- or *para*-positions of these compounds. Study conducted on sonicated kasturi lime juice also showed similar trend of increase in total phenolic content (Bhat et al., 2011). Thus, the effect of ultrasound in juices depends on its content besides processing conditions.

3.4. Ascorbic acid

Ascorbic acid exhibits potential antioxidant activity and is known to protect cells from free radicals induced damage. Ascorbic acid contributes substantially towards prevention of the onset of cardiovascular diseases and cancer (Marín, Martinez, Uribesalgo, Castillo, & Frutos, 2002). Results regarding the effects of ultrasound intensity and processing time on soursop juice ascorbic acid content showed that only the quadratic terms of power intensity and time were statistically significant (95% confidence level) (Eq. (6)). The regression was significant and explained 80% of the variability.

$$AA = 10.50 - 1.79i^2 - 0.62t^2 \quad (6)$$

Ascorbic acid is thermolabile and is highly sensitive to light as well as to various processing conditions, wherein the mechanism of

degradation precedes either aerobic and/or anaerobic pathways (Vieira, Teixeira, & Silva, 2000). Results regarding the effect of sonication treatments on the contents of ascorbic acid of soursop juice are listed in Table 1. It can be observed a reduction in the levels of this content only in assays 2, 4, 8, 9 and 11, however this reduction was less than 34% loss of the initial ascorbic acid content of the unprocessed juice.

It is possible to notice from Fig. 3 that higher ultrasound intensities (greater than 330 W/cm^2) or lower intensities (up to 118 W/cm^2), independent of the processing time resulted in a decrease of the initial ascorbic acid content of the soursop juice. Reports are available on the degradation of ascorbic acid in fruit juice after sonication treatments (Adekunte et al., 2010). However, in our present study, a significant increase in the ascorbic acid content was observed after some sonication treatments, mainly when intermediate ultrasound intensity was used (Fig. 3). Similar observations were done for sonicated apple, guava and kasturi lime juices, wherein an increase in ascorbic acid content was observed (Aadil et al., 2013; Abid et al., 2013; Bhat et al., 2011; Cheng et al., 2007). The increase of ascorbic acid of apple juice was directly attributed to the cavitation during sonication in which no heat is supplied and further it removes the dissolved oxygen, which is essential for ascorbic acid degradation, during cavitation produced during sonication treatments.

Zenker, Heinz, and Knorr (2003) found that sonication had no effect on the ascorbic acid content in milk and orange juice. This was considered somewhat surprising taking into account that manothermosonication treatments are able to produce substantial amounts of hydroxyl radicals (Vercet, Lopez, & Burgos, 1999). The explanation could lie in a competition (different reaction rates) between hydroxyl groups and all the other oxidizable substrates available (i.e. proteins or sugars).

3.5. Color

Color is a visual indicator to judge the quality of fruit juices and plays an important role in consumer satisfaction (Aadil et al., 2013). Color can highlight the acceptance level and can serve as an indicator of microbial quality during processing and storage of a fruit juice (Bhat et al., 2011).

Results regarding the effect of sonication treatments on color values of soursop juice are given in Table 1. It can be observed a slightly increase in L^* values for almost all samples, as compared control. This observation was in agreement with that of sonicated watermelon juice (Rawson et al., 2011), where an increase in lightness value was attributed to the partial precipitation of unstable suspended particles followed by a decrease due to oxidative darkening. However, Tiwari et al. (2008) observed an increase in cloud value due to the homogenization effect of sonication which may explain the increase in L^* value.

The sonicated juice samples showed lower a^* (except for assay 2) and b^* values. These results are in agreement with Tiwari et al. (2008) for sonicated orange juice. Ahmed, Shivhare, and Ramaswamy (2002) reported that any change in Hunter *a,b* values is associated with a simultaneous change in *L* value. Various combinations such as *Lab*, *L*/*ab*, *La*/*b*, *Lb*/*a* of tristimulus *L*, *a*, *b* values have been used to represent the change in visual color of tomato puree and strawberry juice (Rodrigo, van Loey, & Hendrickx, 2007). Recently a study by Zhang et al. (2008) used color density to represent the change in color of pulsed electric field treated blackberry juice. Therefore, color degradation was also reported in terms of *Lab* and total color difference (TCD).

Results regarding the effects of ultrasound intensity and processing time on soursop juice total color difference (TCD) showed that only the processing time quadratic term was not statistically significant (95% confidence level) (Eq. (7)). The regression was significant and explained 86% of the variability.

$$\mathrm{TCD} = 1.26 - 0.77i + 0.07t - 0.10i^2 - 0.14it \quad (7)$$

It can be observed from Fig. 4 a strong effect of ultrasound intensity on TCD. The higher the intensity, higher TCD values were obtained, independent of the processing time.

The color of soursop juice is generally influenced by the existence of natural pigments, which in turn is dependent on the stage of maturity of the fruit, storage conditions employed, enzymatic activity and microbial contamination. The observed color changes in this study may be caused by cavitation, which governs various physical, chemical and biological reactions, such as accelerating chemical breakdown of susceptible particles, such as enzymes and microorganisms (Sala, Burgos, Condón, Lopez, & Raso, 1995). As

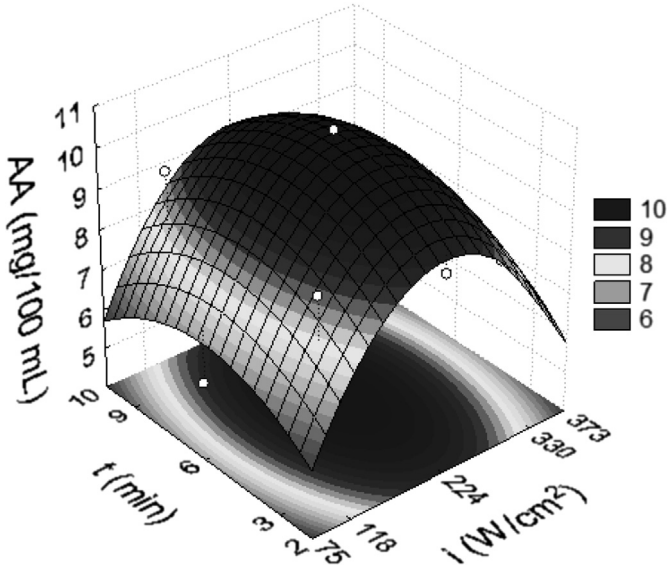

Fig. 3. Response surfaces for soursop juice ascorbic acid content (AA) as a function of power intensity (*i*) and processing time (*t*).

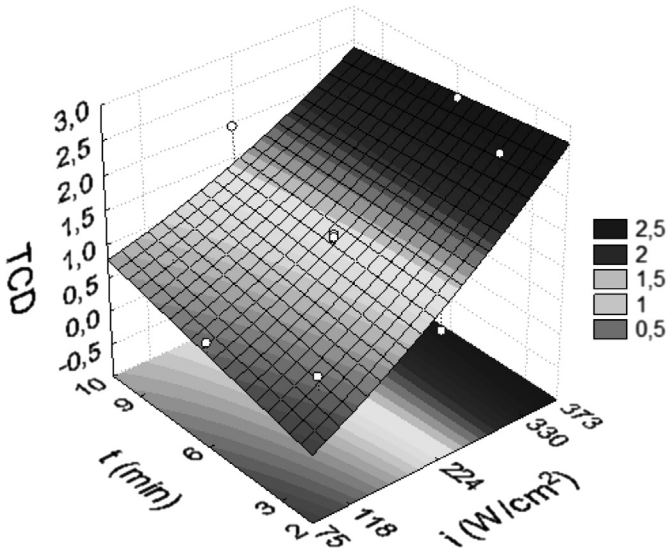

Fig. 4. Response surfaces for soursop juice total color difference (TCD) as a function of power intensity (*i*) and processing time (*t*).

observed by Mason (1991), degradation of color in sonicated juice samples can be attributed to the accelerated carotenoid isomerization as well as to the oxidation reactions that occur as a result of interaction with free radicals generated during sonication treatments. Cavitation induced during sonication has been reported to contribute to changes occurring in the color of fruit juices (Cheng et al., 2007; Tiwari et al., 2008).

For soursop juice, when higher TCD values were obtained (Fig. 4), higher temperature difference (Fig. 2) and lower PPO residual activity (Fig. 1) were obtained. Abid et al. (2014) observed that although the most severe ultrasound treatment significantly reduced the residual PPO and POD (peroxidase) activity in apple juice, the color change indicated the most phenol condensation of all treatments. In addition, as observed by Suslick (1988), color degradation may also be due to extreme physical phenomena (temperature up to 1000 K and pressure up to 500 MPa at microscale) which take place when bubbles collapse.

As discoloration might affect the consumers' preference, optimization of critical processing parameters by estimating interactive and quadratic effects by using Response Surface Methodology (RSM) has been recommended to determine juice quality and have been successful (Bhat et al., 2011; Tiwari et al., 2008). Although sonication treatments induced changes in all color values of soursop 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 soursop juice.

3.6. Sensory evaluation

The sensory evaluation was performed with a control sample (non sonicated) and a sample submitted to ultrasound intensity of 330 W/cm^2 for 9 min. At this condition, it could be obtained lower PPO residual activity, higher temperature difference, a phenolic retention of 71.5% and ascorbic acid retention of 86.7%. TCD was 1.84, but as mentioned before, the changes in sample color was not seen by naked eyes.

The scores attributes are shown in Table 2. There were no significant differences (95% level) between samples for all studied attribute, except for texture. However, the sonicated samples had highest scores for texture (and appearance).

Caminiti et al. (2011) found that a combination of ultraviolet light and manothermosonication that was applied to apple and cranberry juices had a negative effect on the odour and taste of the product. Also, Gómez-López, Orsolani, Martínez-Yépez, and Tapia (2010) observed for sonicated orange juice, from the sensory point of view, that the ultrasonication treatment produced statistically significant decrease in all the sensory parameters tested (color, aroma, flavor, and overall quality), but without driving the scores beyond the rejection limit. For soursop juice, a similar trend was observed for taste and aroma parameters, which had lower scores compared to the non-treated juice, but all within the acceptance range and with no significance difference from the control (non-sonicated) sample.

4. Conclusion

Response surface methodology (RSM) was demonstrated to be an effective technique for investigating the effects of ultrasound intensity and processing time on polyphenol oxidase (PPO) residual activity, temperature increase, phenolic compounds, ascorbic acid content (AA) and total color difference (TCD). Predictive regression models were developed for the estimation of PPO residual activity, temperature increase, AA content and TCD. The coefficient of determination (R^2) for predicted models showed good correlation with the experimental data at a 95% confidence level. This work demonstrates that ultrasound significantly influences key soursop juice quality parameters. Despite the fact that ultrasound was unable to achieve the total inactivation of PPO, thermal treatment at the highest temperature reached due to juice sonication showed no effect on enzyme inactivation, thus attesting that ultrasound is a good non-thermal pretreatment for soursop juice. Color changes observed during sonication were subtle, indicating no major changes in the appearance of the fruit juice. An optimum processing condition using 330 W/m^2 power intensity for 9 min was chosen and submitted to sensorial evaluation, obtaining good acceptance in all studied parameters. Although sonication caused phenolic and some ascorbic acid degradation at some processing conditions, this technology could be suitable for soursop processing to obtain juices with high bioactive compounds retention levels and low PPO residual activity and color changes.

Table 2
Sensory scores for quality attributes of soursop juice.

Sample	Appearance	Aroma	Taste	Texture
Control	7.25 ± 1.35^a	7.64 ± 1.02^a	7.05 ± 1.50^a	6.92 ± 1.65^a
Sonicated	7.66 ± 1.06^a	7.23 ± 1.64^a	6.75 ± 1.57^a	7.57 ± 1.19^b

Any means in the same columns with the same letters are not significantly different ($p > 0.05$).

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References

Aadil, R. M., Zeng, X. A., Han, Z., & Sun, D. W. (2013). Effect of ultrasound treatments on quality of grapefruit juice. *Food Chemistry, 141*, 3201–3206.
Abid, M., Jabbar, S., Bing, H., Hashim, M. M., Wu, T., Lei, S., et al. (2014). Thermosonication as a potential quality engancement technique of apple juice. *Ultrasonics Sonochemistry, 21*, 984–990.
Abid, M., Jabbar, S., Wu, T., Hashim, M. M., Hu, B., Lei, S., et al. (2013). Effect of ultrasound on different quality parameters of apple juice. *Ultrasonics Sonochemistry, 20*, 1182–1187.
Adams, J. B., & Ongley, M. H. (1973). The degradation of anthocyanins in canned strawberries. I. The effect of various processing parameters on the retention of pelargonidin-3-glucoside. *International Journal of Food Science and Technology, 8*, 139–145.
Adekunte, A. O., Tiwari, B. K., Cullen, P. J., Scannell, A. G. M., & O'Donnell, C. P. (2010). Effect of sonication on colour, ascorbic acid and yeast inactivation in tomato juice. *Food Chemistry, 122*, 500–507.
Ahmed, J., Shivhare, U. S., & Ramaswamy, H. S. (2002). A fractional conversion kinetic model for thermal degradation of color in red chilli puree and paste. *LWT-Food Science and Technology, 35*, 497–503.
Ashokkumar, M., Sunartio, D., Kentish, S., Mawson, R., Simons, L., Vilkhu, K., et al. (2008). Modification of food ingredients by ultrasound to improve functionality: a preliminary study on a model system. *Innovative Food Science and Emerging Technology, 9*, 155–160.
Bhat, R., Kamaruddin, N. S. B. C., Min-Tze, L., & Karim, A. A. (2011). Sonication improves kasturi lime (*Citrus microcarpa*) juice quality. *Ultrasonics Sonochemistry, 18*, 1295–1300.
Caminiti, I. M., Palgan, I., Noci, F., Muñoz, A., Whyte, P., & Cronin, D. A. (2011). The effect of pulsed electric fields (PEF) in combination with high intensity light pulses (HILP) on *Escherichia coli* inactivation and quality attributes in apple juice. *Innovative Food Science and Emerging Technology, 12*, 118–123.
Chandrapala, J., Oliver, C., Kentish, S., & Ashokkumar, M. (2012). Ultrasonics in food processing – food quality assurance and food safety. *Trends in Food Science & Technology, 26*, 88–98.
Cheng, L. H., Soh, C. Y., Liew, S. C., & The, F. F. (2007). Effects of sonication and carbonation on guava juice quality. *Food Chemistry, 104*, 1396–1401.
Gómez-López, V. M., Orsolani, L., Martínez-Yépez, A., & Tapia, M. S. (2010). Microbiological and sensory quality of sonicated calcium-added orange juice. *LWT-Food Science and Technology, 43*, 808–813.
Hrazdina, G. (1971). Reactions of the anthocyanidin-3,5-diglucosides: formation of 3,5-di-(O-b-D-glucosyl)-7-hydroxy coumarin. *Phytochemistry, 10*, 1125–1130.
Khuri, A. J., & Cornell, F. A. (1996). *Response surfaces: Design and analyses*. New York: Mercel Dekker.

López, P., Sala, F. J., de la Fuente, J. L., Raso, J., & Burgos, J. (1994). Inactivation of peroxidase, lipoxygenase and poliphenol oxidase by manothermosonication. *Journal of Agricultural and Food Chemistry, 42*, 252–256.

Marín, F. R., Martinez, M., Uribesalgo, T., Castillo, S., & Frutos, M. J. (2002). Changes in nutraceutical composition of lemon juices according to different industrial extraction systems. *Food Chemistry, 78*, 319–324.

Mason, T. J. (1991). *Practical sonochemistry: User's guide to application in chemistry and chemical engineering* (Vol. 22–25) pp. 1–150). UK: Ellis Horwood.

Mawson, R., Gamage, M., Terefe, M. S., & Knoerzer, K. (2011). Ultrasound in enzyme activation and inactivation. In H. Feng, G. V. Barbosa-C_anovas, & J. Weiss (Eds.), *Ultrasound technologies for food and bioprocessing* (pp. 369–404). USA: Springer.

O'Donnell, C. P., Tiwari, B. K., Bourke, P., & Cullen, P. J. (2010). Effect of ultrasonic processing on food ezymes of industrial importance. *Trends in Food Science and Technology, 21*, 358–367.

Oms-Oliu, G., Odriozola-Serrano, I., Soliva-Fortuny, R., & Martín-Belloso, O. (2008). The role of peroxidase on the antioxidant potential of fresh-cut 'Piel de Sapo' melon packaged under different modified atmosphere. *Food Chemistry, 106*, 1085–1092.

Pereira, R. N., & Vicente, A. A. (2010). Environmental impact of novel thermal and nonthermal technologies in food processing. *Food Research International, 43*, 1936–1943.

Pingret, D., Fabiano-Tixier, A. S., & Chemat, F. (2013). Degradation during application of ultrasound in food processing: a review. *Food Control, 31*, 593–606.

Rawson, A., Patras, A., Tiwari, B. K., Noci, F., Koutchma, T., & Brunton, N. B. K. (2011). Effect of thermal and nonthermal processing technologies on the bioactive content of exotic fruits and their products: review of recent advances. *Food Research International, 44*, 1875–1887.

Rodrigo, D., van Loey, A., & Hendrickx, M. (2007). Combined thermal and high pressure colour degradation of tomato puree and strawberry juice. *Journal of Food Engineering, 79*, 553–560.

Sadilova, E., Carle, R., & Stintzing, F. C. (2007). Thermal degradation of anthocyanins and its impact on color and in vitro antioxidant capacity. *Molecular Nutrition and Food Research, 51*, 1461–1471.

Sala, F. J., Burgos, J., Condón, S., Lopez, P., & Raso, J. (1995). Effect of heat and ultrasound on microorganisms and enzymes. In G. W. Gould (Ed.), *New methods of food preservation* (pp. 177–204). London: Blackie Academic & Professional.

Shashirekha, M. N., Baskaran, R., Rao, L. J., Vijayalakshmi, M. R., & Rajarathnam, S. (2008). Influence of processing conditions on flavour compounds of custard apple (Annona squamosa L.). *LWT – Food Science and Technology, 41*, 236–243.

Singleton, V. L., Orthofer, R., & Lamuela, R. M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteau reagent. *Methods in Enzymology, 299*, 152–178.

Strohecker, R., & Henning, H. (1967). *Analisis de vitaminas: métodos comprobados*. Madrid: Paz Montalvo.

Telis-Romero, J., Beristain, C. I., Gabas, A. L., & Telis, V. R. N. (2007). Effect of apparent viscosity on the pressure drop during fluidized bed drying of soursop pulp. *Chemical Engineering and Processing, 46*, 684–694.

Tian, Z. M., Wan, M. X., Wang, S. P., & Kang, J. Q. (2004). Effects of ultrasound and additives on the function and structure of trypsin. *Ultrasonics Sonochemistry, 11*, 399–404.

Tiwari, B. K., O'Donnell, C. P., & Cullen, P. J. (2009). Effect of sonication on retention of anthocyanins in blackberry juice. *Journal of Food Engineering, 93*, 166–171.

Tiwari, B. K., Muthukumarappan, K., O'Donnell, C. P., & Cullen, P. J. (2008). Colour degradation and quality parameters of sonicated orange juice using response surface methodology. *LWT–Food Science and Technology, 41*, 1876–1883.

Valdramidis, V. P., Cullen, P. J., Tiwari, B. K., & O'Donnell, C. P. (2010). Quantitative modeling approaches for ascorbic acid degradation and non-enzymatic browning of orange juice during ultrasound processing. *Journal of Food Engineering, 96*, 449–454.

Vercet, A., Lopez, P., & Burgos, J. (1999). Inactivation of heat-resistant pectinmethylesterase from orange by manothermosonication. *Journal of Agricultural and Food Chemistry, 47*, 432–437.

Vieira, M. C., Teixeira, A. A., & Silva, C. L. M. (2000). Mathematical modeling of the thermal degradation kinetics of vitamin in cupuacbu (Theobroma grandiflorum) nectar. *Journal of Food Engineering, 43*, 1–7.

Wan, J., Mawson, R., Ashokkumar, M., Ronacher, K., Coventry, M. J., & Roginski, H. (2005). Emerging processing technologies for functional foods. *Australian Journal of Dairy Technology, 60*, 167–169.

Wissemann, K. W., & Lee, C. Y. (1980). Polyphenoloxidase activity during grape maturation and wine production. *American Journal of Enology and Viticulture, 31*, 206–211.

Yemenicioglu, A., & Cemeroglu, B. (2003). Consistency of polyphenol oxidase (PPO) thermostability in ripening apricots (Prunus armeniaca L.): evidence for the presence og thermostable PPO forming and destabilizing mechanisms in apricots. *Journal of Agricultural and Food Chemistry, 51*, 2371–2379.

Zenker, M., Heinz, V., & Knorr, D. (2003). Application of ultrasound-assisted thermal processing for preservation and quality retention of liquids foods. *Journal of Food Protection, 66*, 1642–1649.

Zheng, L., & Sun, D. W. (2006). Innovative applications of power ultrasound during food freezing process- A review. *Food Science and Technology, 17*, 16–23.