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Effects of Sonication on the Kinetics of Orange Juice Quality Parameters

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The effects of sonication on pH, °Brix, titratable acidity (TA), cloud, browning index, and color parameters (L^*, a^*, and b^*) of freshly squeezed orange juice samples were studied. Ultrasonic intensity (UI) levels of 8.61, 9.24, 10.16, 17.17, and 22.79 W/cm^2 and treatment times of 0 (control), 2, 4, 6, 8, and 10 min were investigated. No significant changes in pH, °Brix, and TA ($p < 0.05$) were found. Cloud value, browning index, and color parameters were significantly affected by ultrasonic intensity and treatment time. Changes in cloud value followed first-order kinetics, whereas browning index, L^*, a^*, and b^* values followed zero-order kinetics. Reaction rate constants were linearly correlated ($R^2 > 0.90$) to ultrasonic intensity.

KEYWORDS: Ultrasonic intensity; sonication; browning index; color degradation

INTRODUCTION

Orange juice is the predominant juice processed by the beverage industry worldwide (*1*). Although thermal processing remains the most widely employed pasteurization technique, there is growing interest in the development of alternative preservation techniques that result in minimal changes in organoleptical and nutritional properties (*2*). Nonthermal processing techniques offering potential include electric or magnetic fields, ionizing radiation, pulsed white light, high-hydrostatic pressure (*3, 4*), and ultrasound (*5*).

Ultrasound has been identified as a potential technology to meet the U.S. Food and Drug Administration (FDA) requirement of a 5 log reduction in pertinent microorganisms found in fruit juices (*6*). When high-power ultrasound propagates in a liquid, cavitation bubbles are generated due to pressure changes. These microbubbles collapse violently in the succeeding compression cycles of a propagated sonic wave. Ultrasound has been studied for microbial inactivation in fruit juices including apple cider (*7*), orange juice (*8*), guava juice (*9*), and tomato juice (*10*). Zang (*11*) studied the inactivation of pectin methylesterase (PME) in orange juice and advocated the development of an ultrasound-assisted orange juice process.

Cloud stability is a critical orange juice quality parameter imparting characteristic flavor, color, and mouthfeel to orange juice. Orange juice color is a primary factor considered by the consumer in determining juice quality (*12*) and can be correlated with both sensorial and nutritional quality attributes (*13*). Fruit juice color is principally attributed to various carotenoid compounds, including α-, β-, and ζ-carotene, antheraxanthin, auroxanthin, leutin, luteoxanthin, mutatoxanthin, violaxanthin, zeaxanthin, zeinoxanthin, and β-cryptoxanthin (*14*). Several color scales have been used to describe color; those most frequently used in the food industry are the Hunter color values (L, a, b), CIE systems, and the Munsell color solids (*15*).

Kinetic models have been developed to evaluate color degradation and browning reactions during high-pressure processing (*16*) and pulsed electric field (PEF) (*17*) treatment of orange juice. However, such kinetic studies have not been reported for ultrasonic processing of orange juice. The objective of this study was to investigate the effect of ultrasonic intensity on critical orange juice quality parameters and to model the kinetics of color, browning index, and cloud value as a function of ultrasonic intensity.

MATERIALS AND METHODS

Preparation of Orange Juice Samples. Fresh oranges (*Citrus sinensis* cv. Valencia) harvested in June 2007 were purchased from a local fruit market (Reilly Wholesale Ltd., Dublin, Ireland). Juice was obtained using a citrus juice extractor (Braun GmbH, Kronberg, Germany). Recoverable juice yield was ca. 35% from a total of 350 oranges, The juice was immediately filtered on a double layer of cheesecloth to remove pulp from the freshly squeezed orange juice and sonicated.

Ultrasound Treatment. A 1500 W ultrasonic processor (VC 1500, Sonics and Materials Inc.) with a 19 mm probe was used for sonication. Samples were processed at a constant frequency of 20 kHz. The energy input was controlled by setting the amplitude of the sonicator probe. Ultrasonic intensity levels (8.61, 9.24, 10.16, 11.78, 13.28 17.17, and 22.79 W/cm^2) and treatment times (2, 4, 6, 8, and 10 min) were varied

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Table 1. Effect of Ultrasonic Intensity (UI) and Treatment Time on Titratable Acidity (TA), pH, and °Brix of Orange Juice[a]

		control			treated		
UI (W/cm^2)	treatment time (min)	TA	pH	°Brix	TA	pH	°Brix
8.61	2–10	0.63	3.61	8.9	0.63	3.61	8.9
9.24	2–10	0.63	3.62	8.8	0.63	3.62	8.8
10.16	2–10	0.64	3.61	8.9	0.64	3.61	8.9
11.78	2–10	0.63	3.61	8.9	0.63	3.61	8.9
13.28	2–10	0.64	3.62	8.8	0.64	3.62	8.8
15.08	2–10	0.63	3.62	8.9	0.63	3.62	8.9
17.17	2–10	0.63	3.62	8.9	0.63	3.62	8.9
22.79	2–10	0.63	3.62	8.9	0.63	3.62	8.9

[a] Values are means ($n = 3$).

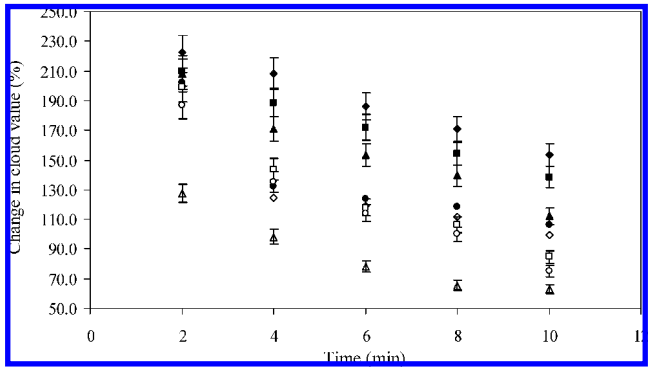

Figure 1. Changes in cloud value (percent) for orange juice during ultrasonic processing at (◆) 8.61 W/cm^2, (■) 9.24 W/cm^2, (▲) 10.16 W/cm^2, (●) 11.78 W/cm^2, (◇) 13.28 W/cm^2, (□) 15.08 W/cm^2, (○) 17.17 W/cm^2, and (△) 22.79 W/cm^2 intensity levels.

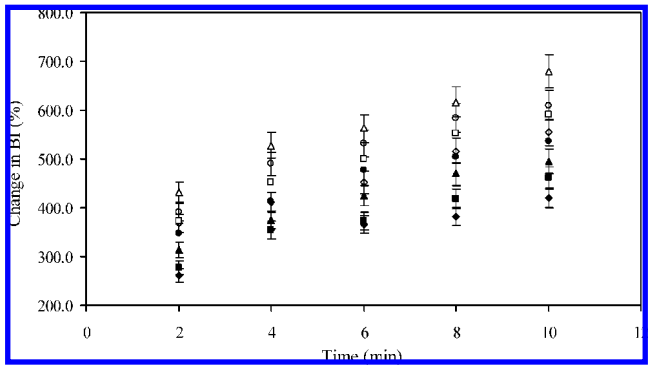

Figure 2. Changes in browning index (BI) (percent) for orange juice during ultrasonic processing at (◆) 8.61 W/cm^2, (■) 9.24 W/cm^2, (▲) 10.16 W/cm^2, (●) 11.78 W/cm^2, (◇) 13.28 W/cm^2, (□) 15.08 W/cm^2, (○) 17.17 W/cm^2, and (△) 22.79 W/cm^2 intensity levels.

with pulse durations of 5 s on and 5 s off. These amplitude levels and processing times were selected on the basis of inactivation studies for *Escherichia coli* ATCC 25922 carried out with model juices prior to this study. Eighty milliliter orange juice samples were placed in a 100 mL jacketed vessel through which water at 25 ± 1.0 °C and a flow rate of 0.5 L/min was circulated. The ultrasound probe was submerged to a depth of 2.5 cm in the sample. All treatments were carried out in triplicate.

Estimation of Ultrasonic Intensity. Ultrasonic intensity was determined using a calorimetric method. Orange juice samples were sonicated at a particular amplitude level, with temperature T recorded as a function of time under adiabatic conditions using a T-type thermocouple (RS-1315, Radionics, Dublin, Ireland). From temperature versus time data, the initial temperature rise dT/dt was determined by polynomial curve fitting. The ultrasonic power P was determined by

$$P = mC_p(\mathrm{d}T/\mathrm{d}t)_{t=0} \quad (1)$$

where (dT/dt) is the change in temperature over time (°C s^{-1}), C_p is the specific heat of orange juice (3.73 kJ kg^{-1} °C^{-1}), and m is the mass (kg).

Ultrasonic intensity was calculated using

$$\mathrm{UI} = \frac{4P}{\pi D^2} \quad (2)$$

where UI is ultrasonic intensity (W/cm^2), P is power (W), and D is probe diameter (1.9 cm).

Cloud Value. Orange juice samples (5 mL) were centrifuged (Sigma 1A, AGB Scientific Ltd., Dublin, Ireland) at 756g for 10 min at room temperature (20.0 ± 0.5 °C). Cloud value was measured as supernatant absorbance at 660 nm using a Unicam UV–Vis (UV2) spectrophotometer with distilled water serving as a blank (*18*).

pH Determination. The pH of treated and untreated orange juice samples was measured using a digital pH-meter (model 420A, Orion Bench top pH meter, Allometrics Inc.). The meter was calibrated with commercial buffer solutions at pH 7.0 and 4.0. Samples (10 mL) were placed in a 50 mL beaker with a magnetic stirrer and pH electrode inserted. Samples were measured at 20 ± 0.5 °C.

Total Solids (°Brix). Soluble solids were measured using a refractometer (Abbe 60, Bellingham + Stanley Ltd.). Refractive index was recorded and converted to °Brix. Measurements were performed at 20.0 ± 0.5 °C. The refractometer prism was cleaned with distilled water after each analysis.

Titratable Acidity (TA). Samples of 20 mL were placed into a 250 mL beaker, and 80 mL of distilled water was added. This solution was then titrated against standardized 0.1 N NaOH (Sigma-aldrich, Dublin, Ireland) to the phenolphthalein end point (pH 8.2 ± 0.1). The volume of NaOH was converted to grams of citric acid per 100 mL of juice (*19*), and TA was calculated using

$$\mathrm{TA} = \frac{[V \times 0.1\mathrm{N}\mathrm{NaOH} \times 0.067 \times 100]}{m} \quad (3)$$

where V is titer volume of NaOH and m is mass of orange juice (g).

Browning Index (BI). The BI was measured using the method of Meydav et al. (*20*). A 10 mL orange juice sample was centrifuged (10 min, 756g) (Sigma 1A, AGB Scientific Ltd., Dublin, Ireland) to remove coarse particles from the sample. Five milliliters of ethyl alcohol (95%, Sigma-Aldrich, Dublin, Ireland) was added to 5 mL of juice supernatant and centrifugation was repeated. The absorbance of the supernatant was obtained at 420 nm using a Unicam UV–Vis (UV2) spectrophotometer.

Color Determination. After sonication, orange juice samples were cooled to room temperature (20 ± 1.0 °C). Color was measured using a Hunter Laboratory colorimeter (ColorFlex, model A60-1010-615, Hunter Associates Laboratory Inc., Reston, VA) based on three color coordinates, namely, L^*, a^*, and b^*. The instrument (65°/0° geometry, D25 optical sensor, 10° observer) was calibrated using white ($L = 92.8$; $a = -0.8$, $b = 0.1$) and black reference tiles. Color values were expressed as L^* (whiteness or brightness/darkness), a^* (redness/greenness), and b^* (yellowness/blueness). Total color difference (TCD) was determined using eq 4, which indicates the magnitude of color change after treatment. Color measurements were taken in triplicate.

$$\mathrm{TCD} = \sqrt{(L^* - L_0)^2 + (a^* - a_0)^2 + (b^* - b_0)^2} \quad (4)$$

where L_0, a_0, and b_0 are color values of untreated juice.

Kinetic Modeling. Kinetic models were developed using a two-step procedure (*21*). Reaction rate constants were determined by fitting the experimental data to zero-order (eq 5) and first-order (eq 6) kinetic models

$$C = C_0 + k_0 t \quad (5)$$

$$C = C_0 \mathrm{e}^{k_1 t} \quad (6)$$

where C is the studied parameter (i.e., $A_{660\mathrm{nm}}$, $A_{420\mathrm{nm}}$, L^*, a^*, b^*) at any given reaction time, C_0 are initial values of untreated samples (L_0, a_0, b_0), and k_0 and k_1 are reaction rate constants.

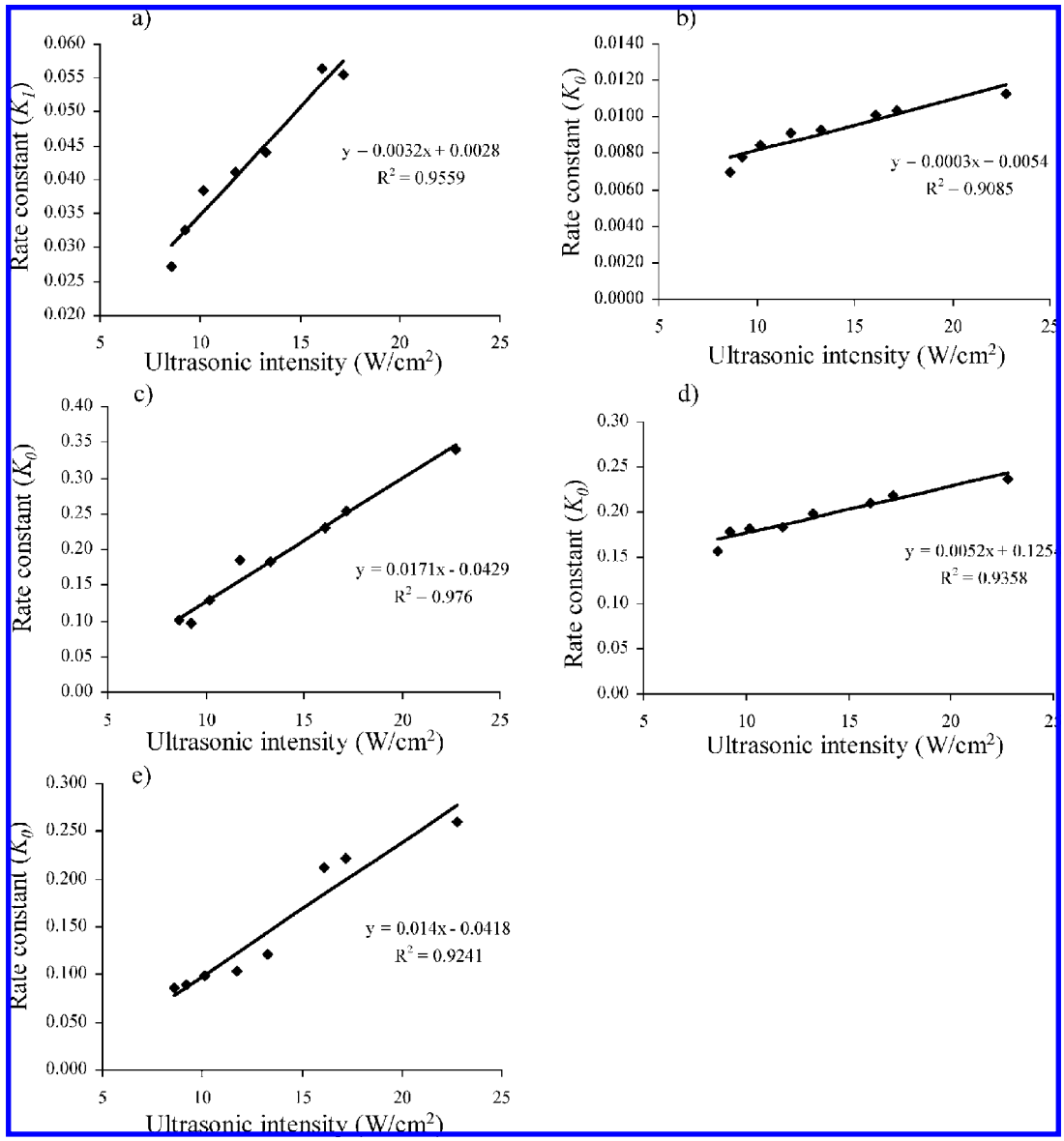

Figure 3. Modeling of reaction rate constants for (**a**) cloud (A_{660nm}), (**b**) browning index (A_{420nm}), (**c**) L^*, (**d**) a^*, and (**e**) b^*.

In the second step the rate constants were modeled as a function of ultrasonic intensity. Data fitting was considered to be significant at a probability level of 95%.

Statistical Analysis. A general factorial design (SAS V.9.1, SAS Institute, Cary, NC) consisting of 144 experimental trials was employed. Means and standard deviations were calculated for each treatment. Analysis of variance (ANOVA) was carried out to determine any significant differences ($p < 0.05$) among the applied treatments. Tukey's studentized range test ($p < 0.05$) was applied to compare the average values obtained.

RESULTS AND DISCUSSION

TA, pH, and °Brix. TA, pH, and °Brix for control samples were 0.63 g of citric acid/100 mL of juice, 3.61, and 8.9, respectively. Ultrasonic processing was found to have no significant effect on TA, pH, or °Brix (**Table 1**), irrespective of ultrasonic intensity (W/cm^2) or time ($p < 0.05$). These results are in agreement with Kim et al. (*22*) for orange juice and with Ugarte-Romero et al. (*7*) for apple cider processed with power ultrasound. Similar results were reported for pasteurized orange juice processed with high hydrostatic pressure (*23*) and PEF (*1*).

Cloud. Sonification was found to significantly enhance the cloud value of orange juice. At the lowest UI (8.61 W/cm^2) and treatment time (2 min), cloud was found to increase by 222%. These values decreased with increasing ultrasonic intensity and treatment time. However, at the highest UI (22.79 W/cm^2) and treatment time (10 min) the increase in cloud was 63% over the control (**Figure 1**). Regression analysis was employed to determine the rate constants for the change in cloud value from the maximum cloud gain. Cloud value followed first-order kinetics with increasing intensity level and sonication time ($R^2 > 0.90$). Reaction rate constants (K_1) were calculated using eq 6. The rate constants increased linearly with ultrasonic intensity ($R^2 = 0.95$) (**Figure 3a**). Cloud is related to suspension of particles composed of a complex mixture of protein, pectin, lipids, hemicellulose, cellulose, and other minor components (*24, 25*). It has been reported that the degree of esterification of the pectin backbone necessary to cause cloud loss in orange juice is <36% (*26, 27*). Studies conducted by Seshadri et al. (*28*) suggest that the application of ultrasound breaks the linear pectin molecule, reducing its molecular weight and thus resulting in weaker network formation. Previous studies conducted by Knorr

Table 2. Changes in Hunter Color Values at Various Intensity Levels and Sonication Times[a]

time (min)	8.61 W/cm^2	9.24 W/cm^2	10.16 W/cm^2	11.78 W/cm^2	13.28 W/cm^2	15.08 W/cm^2	17.17 W/cm^2	22.79 W/cm^2
				Lightness Value (L^*)				
0 (control)	59.72 ± 0.09d	59.71 ± 0.09d	59.74 ± 0.09e	59.70 ± 0.09e	59.73 ± 0.09e	59.69 ± 0.09f	59.70 ± 0.09d	59.73 ± 0.09e
2	62.11 ± 0.20a	62.18 ± 0.23a	62.03 ± 0.10a	62.18 ± 0.08a	62.15 ± 0.10a	63.54 ± 0.09a	62.55 ± 0.52a	62.39 ± 0.43a
4	61.96 ± 0.19ab	61.68 ± 0.29b	61.38 ± 0.09b	61.64 ± 0.43ab	62.07 ± 0.10b	62.64 ± 0.10b	61.66 ± 0.62b	62.13 ± 0.33ab
6	61.90 ± 0.19ab	61.37 ± 0.31b	61.04 ± 0.10c	61.32 ± 0.40bc	61.95 ± 0.10c	61.85 ± 0.10c	61.22 ± 0.56bc	61.90 ± 0.31bc
8	61.67 ± 0.37bc	60.91 ± 0.40c	60.29 ± 0.10d	60.90 ± 0.34cd	61.72 ± 0.11d	61.43 ± 0.10d	60.87 ± 0.43c	61.66 ± 0.29cd
10	61.46 ± 0.40c	60.71 ± 0.28c	60.05 ± 0.10e	60.69 ± 0.31d	61.36 ± 0.10e	60.75 ± 0.10e	60.64 ± 0.43c	61.35 ± 0.27d
LSD	0.4391	0.4128	0.0387	0.5524	0.0399	0.427	0.6641	0.4391
				Red-Green Value (a^*)				
0 (control)	7.43 ± 1.03a	7.53 ± 1.03a	7.32 ± 1.03a	7.39 ± 1.03a	7.38 ± 1.03a	7.41 ± 1.03a	7.42 ± 1.03a	7.44 ± 1.03a
2	6.34 ± 1.09b	6.49 ± 1.07b	6.44 ± 1.10b	6.44 ± 1.15b	6.28 ± 1.04b	6.11 ± 0.98b	6.77 ± 0.99b	6.21 ± 0.91b
4	6.06 ± 1.00bc	6.12 ± 1.04c	6.08 ± 1.05c	6.07 ± 1.10c	6.04 ± 1.01c	5.90 ± 1.01c	6.18 ± 0.97c	5.72 ± 0.94c
6	5.81 ± 0.92cd	5.92 ± 1.02c	5.80 ± 1.02d	5.80 ± 1.03cd	5.95 ± 0.99dc	5.62 ± 1.05d	5.67 ± 0.96d	5.48 ± 0.93d
8	5.45 ± 0.92d	5.66 ± 0.97d	5.55 ± 0.97de	5.54 ± 0.98de	5.81 ± 0.98d	5.31 ± 1.03e	5.36 ± 0.99e	5.28 ± 0.95d
10	5.38 ± 0.92d	5.46 ± 0.96d	5.46 ± 0.98e	5.43 ± 0.98e	5.61 ± 0.96e	5.09 ± 0.98f	5.13 ± 0.94f	5.04 ± 0.94e
				Blue-Yellow Value (b^*)				
0 (control)	56.26 ± 0.37e	56.72 ± 0.37e	56.68 ± 0.37e	56.12 ± 0.37e	56.27 ± 0.34f	56.31 ± 0.37f	56.42 ± 0.37f	56.22 ± 0.37e
2	56.25 ± 0.36e	56.51 ± 0.37e	56.43 ± 0.35e	56.59 ± 0.35e	56.40 ± 0.36e	56.33 ± 0.38e	56.57 ± 0.40e	57.14 ± 0.36d
4	56.57 ± 0.38d	57.30 ± 0.43d	56.54 ± 0.35d	56.83 ± 0.36d	56.56 ± 0.36d	56.56 ± 0.31d	56.83 ± 0.38d	57.91 ± 0.37c
6	56.90 ± 0.39c	57.73 ± 0.42c	56.72 ± 0.34c	56.99 ± 0.36c	56.77 ± 0.27c	56.73 ± 0.35c	57.18 ± 0.39c	58.24 ± 0.42bc
8	57.03 ± 0.38b	58.01 ± 0.49b	56.90 ± 0.35b	57.13 ± 0.36b	57.07 ± 0.35b	56.91 ± 0.35b	57.92 ± 0.42b	58.64 ± 0.42ab
10	57.18 ± 0.38a	58.35 ± 0.43a	57.12 ± 0.35a	57.25 ± 0.35a	57.26 ± 0.35a	57.08 ± 0.35a	58.35 ± 0.36a	58.94 ± 0.37a
LSD	0.0851	0.229	0.0913	0.0652	0.0616	0.0782	0.1289	0.4651

[a] Values followed by the same letter in a column for each of the parameters are not significant.

Table 3. Rate of Change in Cloud (A_{660nm}), Browning Index (A_{420nm}), and Color Values (L^*, a^*, b^*) in Response to Treatment Time Described as Zero- (K_0) and First-Order (K_1) Reaction Kinetics Depending on the Specific Parameter

UI (W/cm^2)	cloud (A_{660nm}) $K_1 \times 10^{-2}$min^{-1}	BI (A_{420nm}) $K_0 \times 10^{-3}$ min^{-1}	L^* $K_0 \times 10^{-2}$ min^{-1}	a^* $K_0 \times 10^{-2}$ min^{-1}	b^* $K_0 \times 10^{-2}$ min^{-1}
8.61	2.7 ± 0.009	7.0 ± 0.001	10.0 ± 0.01	16.0 ± 0.01	8.7 ± 0.006
9.24	3.3 ± 0.001	7.8 ± 0.00	10.0 ± 0.00	18.0 ± 0.02	8.9 ± 0.006
10.16	3.8 ± 0.004	8.5 ± 0.00	13.0 ± 0.02	18.0 ± 0.02	9.9 ± 0.001
11.78	4.1 ± 0.002	9.1 ± 0.00	19.0 ± 0.02	18.0 ± 0.02	10.3 ± 0.002
13.28	4.4 ± 0.001	9.3 ± 0.01	18.0 ± 0.01	20.0 ± 0.01	11.0 ± 0.003
15.08	5.6 ± 0.002	10.1 ± 0.00	23.0 ± 0.02	21.0 ± 0.01	21.2 ± 0.006
17.17	5.5 ± 0.001	10.4 ± 0.00	25.0 ± 0.00	22.0 ± 0.01	22.1 ± 0.007
22.79	5.5 ± 0.001	11.3 ± 0.00	34.0 ± 0.00	24.0 ± 0.01	26.1 ± 0.020

et al. (*29*) showed that the activity of endogenous enzymes of fresh lemon juice were effectively decreased when ultrasound treatment was applied. It was reported that the reduction of PME activity in lemon juice resulted in improved cloud stability due to mechanical damage of the PME protein structure. Effects of ultrasound are often ascribed to several mechanical and sonochemical mechanisms induced by cavitation (*30*). Structural damage of pectin may result from the microjets of liquid generated by the asymmetrical collapse of cavitation bubbles. The resultant high-pressure gradient could also cause fragmentation of macromolecules or other structural modifications.

BI. The BI is one of the parameters that indicates the nonenzymatic browning of orange juice. The BI significantly increased with UI and time (**Figure 2**). At the lowest UI (8.61 W/cm^2) and treatment time (2 min), the BI was found to increase by 261%. The BI followed a zero-order reaction (eq 5) with increasing UI and time. The color change or darkening observed in orange juice may be due to particulate fractions (*31*). Similar changes were reported by Ugarte-Romero et al. (*7*) for sonicated apple cider. Previous kinetics studies on BI reactions based on A_{420nm} measurement in citrus juices (*32*), apple juices (*33*), pear puree (*34*), and pear juice concentrate (*35*) similarly reported zero-order reaction kinetics. K_1 values >1 indicate that nonenzymatic browning predominates over pigment destruction (*36*). K_1 values listed in **Table 3** are <1, indicating pigment (carotenoid) destruction due to sonication. The reaction rate constants (K_0) for the BI followed a linear relationship (R^2 = 0.90) with UI (**Figure 3b**).

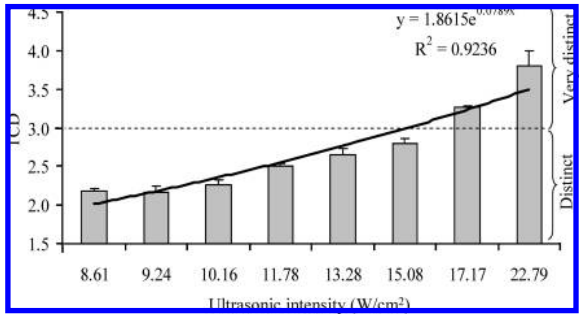

Figure 4. Change in total color difference (TCD) at treatment time of 10 min and ultrasonic intensity (W/cm^2).

Color Kinetics. Significant color differences ($p < 0.05$) were observed for all sonicated samples (**Table 2**). An increase in lightness (L^*) with respect to the control was found at all treatment times and sonication levels. The largest increase was observed at the lowest treatment time for all sonication levels. At treatment times >2 min a subsequent significant ($p < 0.05$) decrease in L^* was recorded as a function of treatment time. A similar profile has been reported by Genovese et al. (*37*) for steam heating of apple juice with the initial increase in L^* attributed to the partial participation of unstable suspended particles followed by a decrease due to oxidative darkening.

The red-green value (a^*) decreased with treatment time and intensity level. However, the blue-yellow value (b^*) significantly increased with treatment time and intensity level (**Table 2**).

The observed color changes may be caused by cavitation, which governs various physical, chemical, or biological reactions, such as accelerating chemical reactions, increasing diffusion rates, dispersing aggregates, or breakdown of susceptible particles such as enzymes and microorganisms (*38*). Orange juice color is mainly due to carotenoid pigments (*39, 40*) and is influenced by product ripening, processing treatments, storage conditions, and browning reactions. Color degradation may be due to the extreme physical conditions that occur during sonication (temperatures up to 5000 K and pressures up to 500 MPa at microscale) (*41*), leading to accelerated carotenoid isomerization (*42*). Zhao et al. (*43*) reported significant effects on carotenoid pigments (astaxanthin), leading to degradation of pigment into colorless compound(s). Carotenoid degradation during ultrasonic processing may be related to oxidation reactions, promoted by the interaction with free radicals formed during sonication (*44*). Hydroxyl radicals produced by cavitation can be involved in the degradation of carotenoid pigments such as α-, β-, and ζ-carotene present in orange juice. Cavities formed by sonication may be filled with water vapor and gases dissolved in the juice, such as O_2 and N_2 (*45*).

To study the kinetics of color degradation, relative changes in lightness, red-green value, and blue-yellow value with reference to the control were studied as a function of sonication time (minutes) at each intensity level. A zero-order kinetics model fitted well ($p < 0.05$) to L^*, a^*, and b^* values with all coefficients of determination (R^2) > 0.90. Reaction rate constants (K_0) listed in **Table 3** were obtained by substituting L^*, a^*, and b^* for C and L_0, a_0, b_0 forC_0 (control value) in eq 5. Reaction rate constants (K_0) were evaluated for zero-, first-, and pseudo-first-order and Arrhenius models. The highest measures of fit were obtained for linear models with $R^2 > 0.92$.

Total color difference (TCD) indicates the magnitude of color difference between sonicated and control samples. Differences in perceivable color can be analytically classified as very distinct (TCD > 3), distinct (1.5 < TCD < 3), and small differences (TCD < 1.5) (*46*). TCD values for this study were found to be either distinct or very distinct, depending upon treatment time or ultrasonic intensity level. **Figure 4** shows the TCD values as a function of UI at the highest treatment time studied. Very distinct changes in TCD were observed only at the two highest UI levels and 10 min of treatment time. An exponential increase in TCD values with respect to UI was observed.

Conclusion. The effect of sonication on selected quality parameters of freshly squeezed orange juice was studied. No significant differences in °Brix, pH, and TA were observed. However, significant changes in browning and color values were found. Also, a significant enhancement of cloud values was observed. Browning index, L^*, a^*, and b^* followed zero-order kinetics, whereas cloud value followed a first-order kinetic. Rate constants (K_0) were found to correlate linearly with ultrasonic intensity. This study shows that the effect of sonication on TCD was either distinct or very distinct.

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