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Stability and Sensory Shelf Life of Orange Juice Pasteurized by Continuous Ohmic Heating

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Electrical heating of food products provides rapid and uniform heating, resulting in less thermal damage to the product. The objective of this research was to examine the effects of ohmic heating on the stability of orange juice with comparison to conventional pasteurization. During storage at 4 °C, degradation curves of ascorbic acid followed a linear decrease pattern in both ohmic-heated and conventionally pasteurized orange juices. For five representative flavor compounds (decanal, octana, limonene, pinene, and myrcene), higher concentrations were measured during storage in the ohmic-heated orange juice than in conventionally pasteurized juice. Although residual pectin esterase activity remained negligible in both types of juices, particle size was lower in the ohmic-heated orange juice. The sensory shelf life was determined by using the Weibull−Hazard method. Although both thermal treatments prevented the growth of microorganisms for 105 days, the sensory shelf life of ohmic-treated orange juice was >100 days and was almost 2 times longer than that of conventionally pasteurized juice.

KEYWORDS: Ohmic heating; orange juice; pasteurization; shelf life

INTRODUCTION

Ohmic heating occurs when an electric current is passed through food, resulting in a temperature rise in the product due to the conversion of the electric energy into heat. The advantages of ohmic heating include uniform heating of food products and a very high-temperature−short-time process (*1*). Therefore, a high-quality product with minimal structural, nutritional, or sensorial changes can be manufactured in a short operating time (*2*). Although the technology of ohmic heating appears to be promising and highly effective, there is little information found in the literature concerning the effects of this technique on specific food products. In this research we focused on orange juice as a model system, because it combines several quality parameters, such as inactivation of microorganisms and enzymes, heat sensitive compounds, and physical characteristics.

Several attempts have been made to examine the influence of different processing techniques on the quality and shelf life stability of orange juice. Nagy et al. (*3*), Roig et al. (*4*), Kaanane et al. (*5*), and Kennedy et al. (*6*) studied the kinetics of ascorbic acid degradation in pasteurized orange juice during storage as a possible marker for the end of shelf life. High-pressure processing was investigated as a means to preserve cloud in freshly squeezed orange juice. Pressures from 500 to 900 MPa were applied at dwell times of 1 s, 1 min, and 10 min. Cloud loss was monitored during storage for 90 days at refrigerated conditions. Higher pressures and longer processing times were more effective at preserving the cloud (*7*). Ayhan et al. (*8*) and Yeom et al. (*9*) conducted a shelf life experiment to examine the stability of pulsed electric field (PEF) processed orange juice. Single-strength orange juice was processed under conditions of 35 kV/cm for 59 μs and stored in glass bottles at 4 and 22 °C. The processed juice was microbiologically stable for 112 days at both storage temperatures. Sensory panel evaluation showed no significant change in overall flavor score during storage at 4 °C for 112 days. Finally, the concentration of ascorbic acid in PEF-treated orange juice reached the critical level of 25 mg/100 mL at 4 °C after 47 days.

The objectives of our study were to examine the influence of ohmic heating on the quality and shelf life stability of orange juice compared to that of conventionally pasteurized orange juice.

MATERIALS AND METHODS

Preparation and Processing of Orange Juice. Shamuti oranges (Somitz Ltd., Ramat-Tzvi, Israel) were processed in a citrus juice extractor 291 (FMC Co., Lakeland, FL) to produce freshly squeezed juice. Orange juice was filtered using a sieve for the separation of large particles (1 mm diameter holes). The fresh orange juice was thermally processed in a 50 kW pilot-scale Electroheating system (Raztek, Sunnyvale, CA; **Figure 1**). The system consists of two feeding tanks: one for a salt solution and the other for the untreated product. The untreated product continuously enters the system via a mono pump (A. P. V. Baker, Peterborouth, U.K.). Initially, the product is pumped to the first part of the system, the rapid cooler where the product is preheated (*10, 11*). The rapid cooler consists of a tank containing two sets of coiled tubes: an upper coil tube for the untreated product flow

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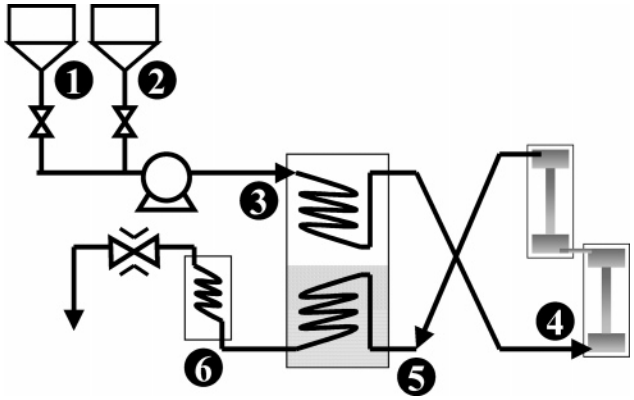

Figure 1. Scheme of the Electroheating system, including salt solution tank (1), product tank (2), preheating (3), electroheating (4), rapid cooling (5), and secondary cooling (6).

and a lower coil for the heated product flow. The upper part of the tank is saturated with steam, and the lower part is filled with water, and the whole system is under vacuum to maximize the heat transfer. The hot product passes through the tube, the water is quickly boiled, and the cold product passes through the tube above the boiled liquid and is heated by the steam condensation. Following preheating, the product enters the electroheater at a temperature that is the exact mean between its temperature at the tank (point 3, **Figure 1**) and the treatment temperature (point 5, **Figure 1**) (*12*−*15*). The electroheating unit consists of two pairs of adjacent graphite electrodes, with a 20 cm gap between each pair of electrodes. The product flows along the axis between the electrodes. The system utilizes alternating current at a frequency of 50 Hz and at maximum voltage of 8 kV. The system controller automatically determines the necessary current and voltage using a feedback from a thermocouple at the exit from the heating chamber to heat the product to the predetermined treatment temperature. Following electroheating, the product enters a 120 cm holding tube, in which the thermal treatment takes place. This tube connects the exit of the electroheater to the entry of the rapid cooler (point 5, **Figure 1**). Then the product is cooled rapidly in the lower part of the rapid cooler. Finally, the product is cooled to room temperature in a tubular heat exchanger.

The installation was pressurized with a pressure valve to provide a backpressure of ∼12 atm and prevent boiling of the superheated product. A presterilization step of the electroheating system was carried out by circulating a sodium chloride solution with the same electrical conductivity of orange juice (σ = 0.36 S/m at 25 °C) at 120 °C for >20 min. After processing, orange juice samples were collected aseptically into sterilized jars for analysis and stored on ice for up to 0.5 h until analyzed or stored at 4 °C.

The F values were calculated with 120 °C as the reference temperature, on the basis of z = 10 °C, which was taken as a representative for the z value of pectin esterase (PE) ranging from 6.5 to 13 °C in the temperature range of 80−90 °C (*16*, *17*). Conventional pasteurization of fresh orange juice was conducted at 90 °C for 50 s using a plate heat exchanger (A. P. V. Baker) with a 1 L holding tube. The corresponding F value is 8.33×10^{-3} min. The set points of the ohmic heating system were selected to achieve a similar F.

Microbial Counts. Microbial counts followed Israeli standard 885, "Microbiological test methods for foodstuffs: general laboratory rules", which follows ISO 7218-1996, "Microbiology of food and animal feeding stuffs—general rules for microbiological examinations" methods. Inactivation of microorganisms by thermal treatments was determined by total plate counts of the heated samples using orange serum agar (OSA), and yeast and mold counts were determined by using oxytetracycline glucose yeast extract agar (OGYE) with a selective supplement. OSA, OGYE, and OGYE selective supplement were purchased from Oxoid (Hampshire, U.K.). Samples of 1 mL of fresh and treated orange juice were diluted with 0.1% peptone water (Bactro, Sparks, MD) to 10^{-1} dilution. From each dilution, two samples were plated. Plates were incubated at 30 °C for 48 h.

Pectin Esterase Activity. Determination of residual PE activity after thermal treatments was based on the formation of galacturonic acid and determined titrimetrically as described by Rouse and Atkins (*18*). Specifically, a 3 mL aliquot of orange juice sample was added to 50 mL of substrate solution containing 1.0% citrus pectin (Fluka, Buchs, Germany) and 0.2 M NaCl (Bio-lab, Jerusalem, Israel). During hydrolysis at 30 °C, the pH was maintained at 7.5 by the addition of 0.1 N NaOH (Antibioticos, Ronado, MI) using an automatic pH-stat (Titrino 718, Metrohm, Switzerland). The consumption of 0.1 N NaOH was recorded during a 10 min reaction period. PE activity unit (PEU) and the relative PE activity (percent) were calculated according to the following equations:

$$\text{PEU} = \frac{(\text{mL of NaOH}) \times (0.1\text{ N NaOH})}{(3\text{ mL of sample}) \times (10\text{ min})} \times 10^4$$

$$\text{relative PE activity (\%)} = \frac{\text{PEU of thermally treated orange juice}}{\text{PEU of fresh orange juice}} \times 100$$

Vitamin C Concentration. Ascorbic acid concentration determination in orange juice was performed according to the method of Yeom et al. (*9*). The analysis was conducted using a reverse-phase high-performance liquid chromatograph (RP-HPLC), HP 1100, equipped with a diode array detector at 254 nm, and controlled by ChemStation software package (Hewlett-Packard, Wilmington, DE). HPLC analysis was carried out on a reverse-phase C_{18} column (25 cm × 4.6 mm SupelcoSil column, Supelco Inc., Bellefonte, PA). Samples were eluted at a flow rate of 1 mL/min with 10% methanol in water solution, brought by citrate to pH 2.9, as a mobile phase. The mobile phase was filtered using a 0.45 μm membrane filter (Millipore, Bedford, MA). The orange juice samples were centrifuged at 12500*g* for 10 min in a 4214 ACL microcentrifuge (ACL International, Milano, Italy) to remove pulp and coarse cloud particles. Twenty microliters of the supernatant was injected manually to the column. The elution time of ascorbic acid and dehydroascorbic acid was 3.4 min for both compounds. The standard calibration curve of L-ascorbic acid (Aldrich Chemical Co., Milwaukee, WI) in concentrations ranging from 10 to 80 mg/100 mL was used to quantify vitamin C.

Flavor Compound Analysis. Measurements of flavor compounds in orange juice were performed by headspace solid-phase microextraction gas chromatography (SPME-GC) following the method of Jia et al. (*19*). A 1.0 mL aliquot of fresh and thermally treated orange juice was transferred into a sealed 7 mL vial. A SPME fiber with 65 μm polydimethylsiloxane−divinylbenzene (Supelco, Inc.) coating was manually inserted into the headspace of the vial containing orange juice for adsorption of the flavor compounds. The vial was incubated at 60 °C for 20 min. The SPME fiber was then injected into the GC injection port at 220 °C and kept for 2 min. The separation of the flavor compounds was accomplished by a Hewlett-Packard 6890 GC equipped with a capillary column (Innowax, 30 m × 0.25 mm i.d., 0.25 μm, Agilent Technologies, Palo Alto, CA) and a flame ionization detector. The temperature was programmed from 60 to 180 °C at rate of 5 °C/min and held for a final 2 min. The GC chromatograph peak area was calculated using the ChemStation software package (Hewlett-Packard). The identification of flavor compounds in orange juice was preformed by comparing the retention time with that of five standard compounds: α-pinene, myrcene, limonene, octanal, and decanal (Sigma Chemical Co., St. Louis, MO). The standard calibration curve of each flavor compound was obtained by plotting the GC peak area against a known concentration in deodorized orange juice.

Browning Measurement. Browning was determined on the basis of the method of Meydav et al. (*20*) and Yeom et al. (*9*). Specifically, orange juice was centrifuged at 12500*g* for 10 min in a 4214 ACL microcentrifuge (ACL International). Supernatant was collected and clarified utilizing a 0.45 μm filter (Millipore). The browning index was measured at 420 nm in a spectrometer (Ultraspec 2100, Biochrom, Cambridge, U.K.) at room temperature.

Particle Size Analysis. The particle size of orange juice was measured by a particle size analyzer (Coulter LS230, Beckman Coulter Co., Miami, FL), equipped with a polarization intensity differential

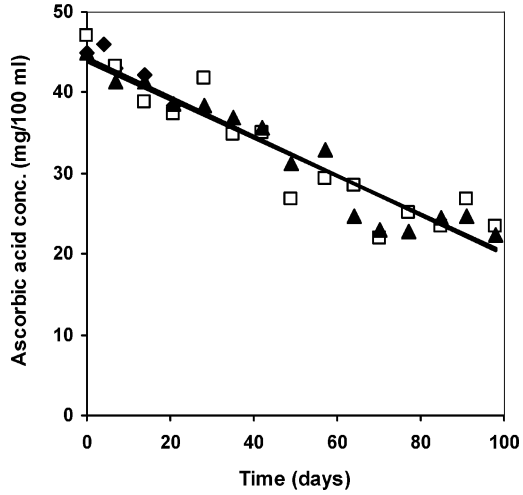

Figure 2. Ascorbic acid concentration in fresh (◆), ohmic-heated (▲), and conventionally pasteurized (□) orange juice during storage.

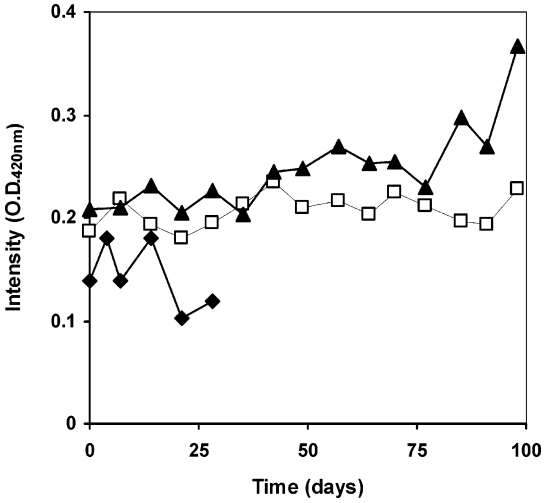

Figure 3. Effects of electrical heating and conventional pasteurization on the browning index of fresh (◆), ohmic-heated (▲), and conventionally pasteurized (□) orange juice during storage at 4 °C.

scattering system. This method is based on laser diffraction analysis. When a parallel beam of a laser passes through the suspension, the diffracted light is focused onto a detector. The detector senses the distribution of scattered light intensity. Particles of a given size diffract light through a given angle, which increases with decreasing particle size. Particle size distribution was calculated and expressed as $D[4,3]$, which is the volume-weighted mean diameter, $D[3,2]$, which is the surface area weighted mean diameter, and $D[1,0]$, which is the arithmetic mean diameter.

Weibull−Hazard Shelf Life Determination. The Weibull−Hazard method is a direct approach to measure the probability of failure and is therefore used to determine the end of shelf life. According to Labuza et al. (*21*), when using the Weibull−Hazard method, one can define shelf life as the time when 50% of untrained tasters find a product unacceptable. Testing was conducted with five panelists along the shelf life and every 7 days. When 50% of the panelists identified the product as unacceptable, an acceleration phase of the study began. At this point, testing was continued at intervals of 4 days. In addition, the number of panelists was enhanced by $C + N$, with N equal to the number of panelists that rated the sample as unacceptable in the previous testing time. The results from the acceptability scoring were tabulated in a hazard-ranking table, which calculates both the hazard and the cumulative hazard for each sample. The results from the hazard-ranking table were plotted on a log−log scale with cumulative hazard on the *x*-axis and time on the *y*-axis. The end of shelf life is determined when the cumulative hazard equals 69.3. At this point, 50% of the panelists would find the sample to be unacceptable.

Data and Statistical Analysis. All experiments were performed in replicates, and the results are expressed as the average. Statistical analysis was performed for the determination of significant differences in the processing treatments. Statistical analysis was conducted with JMP 4.0.4, statistical discovery software (SAS Institute Inc.), and the data analysis tool pack of the Microsoft Excel software.

RESULTS AND DISCUSSION

Change in Vitamin C Content during Storage. The concentration of vitamin C in orange juice is one of its most important attributes for the consumer. Thus, we followed its degradation during storage, to examine whether its pasteurization by ohmic heating affects its stability. The effects of ohmic heating and conventional pasteurization on the concentration of ascorbic acid during storage are shown in **Figure 2**. Degradation curves of ascorbic acid followed a linear decrease in both ohmic-heated and conventionally pasteurized orange juices during storage at 4 °C ($r^2 = 0.923$, $p < 0.0001$). No significant difference was observed in the concentration of ascorbic acid between ohmic heating and conventional pasteurization. As it appears, neither electrical heating nor conventional pasteurization had any influence on the degradation rate of ascorbic acid. Generally, the literature is unclear whether the reaction kinetics of ascorbic acid degradation in pasteurized orange juice during storage is zero or first order (*3*−*6*). Lima et al. (*22*), for example, reported a pseudo-first-order kinetics for both conventional and ohmic heating at 65, 75, 80, and 90 °C. It should be noted, however, that zero order could also be used to model the reaction under the temperature range tested in their research.

Browning in Orange Juice during Storage. Color deterioration and, in particular, browning significantly affect the overall perception of orange juice quality. Browning, which occurs in orange juice during storage, may be accelerated due to abusive storage conditions, the presence of oxygen or metal ions, and above all degradation of ascorbic acid, which provides reactive carbonyl groups that can be precursors to nonenzymatic browning. The effects of ohmic heating and conventional pasteurization on the browning index in orange juice during storage are shown in **Figure 3**.

The browning measurements show significant increase in the browning values in ohmic-heated orange juice compared to browning levels in conventionally pasteurized juice during storage ($p < 0.0001$). In ohmic-heated orange juice absorbance values are stable until day 35. From that day on, there is a continuous increase in browning index up to level of 0.367, which is yet invisible to the human eye (*6*). Such increase in browning after an initial lag period was observed by Roig et al. (*4*). During this period, colorless compounds are probably formed, which do not contribute to the increase in absorbance. The levels of browning in conventionally pasteurized orange juice did not change dramatically during storage and were dispersed around the value of 0.2 ± 0.03. Measurements of color in ohmic-heated and pasteurized orange juice during storage at 4 °C showed no significant difference in whiteness (L value).

Alterations in Flavor Compounds during Storage. Flavor compounds are a major contributor to the unique aroma of orange juice. These characteristic compounds do not exhibit high stability due to the presence of microorganisms and exposure to high temperatures. The results of effects of electrical heating and conventional pasteurization on flavor compounds in orange juice during storage are presented in **Figure 4**.

The concentrations of five representative flavor compounds were measured during storage in fresh, conventionally pasteur-

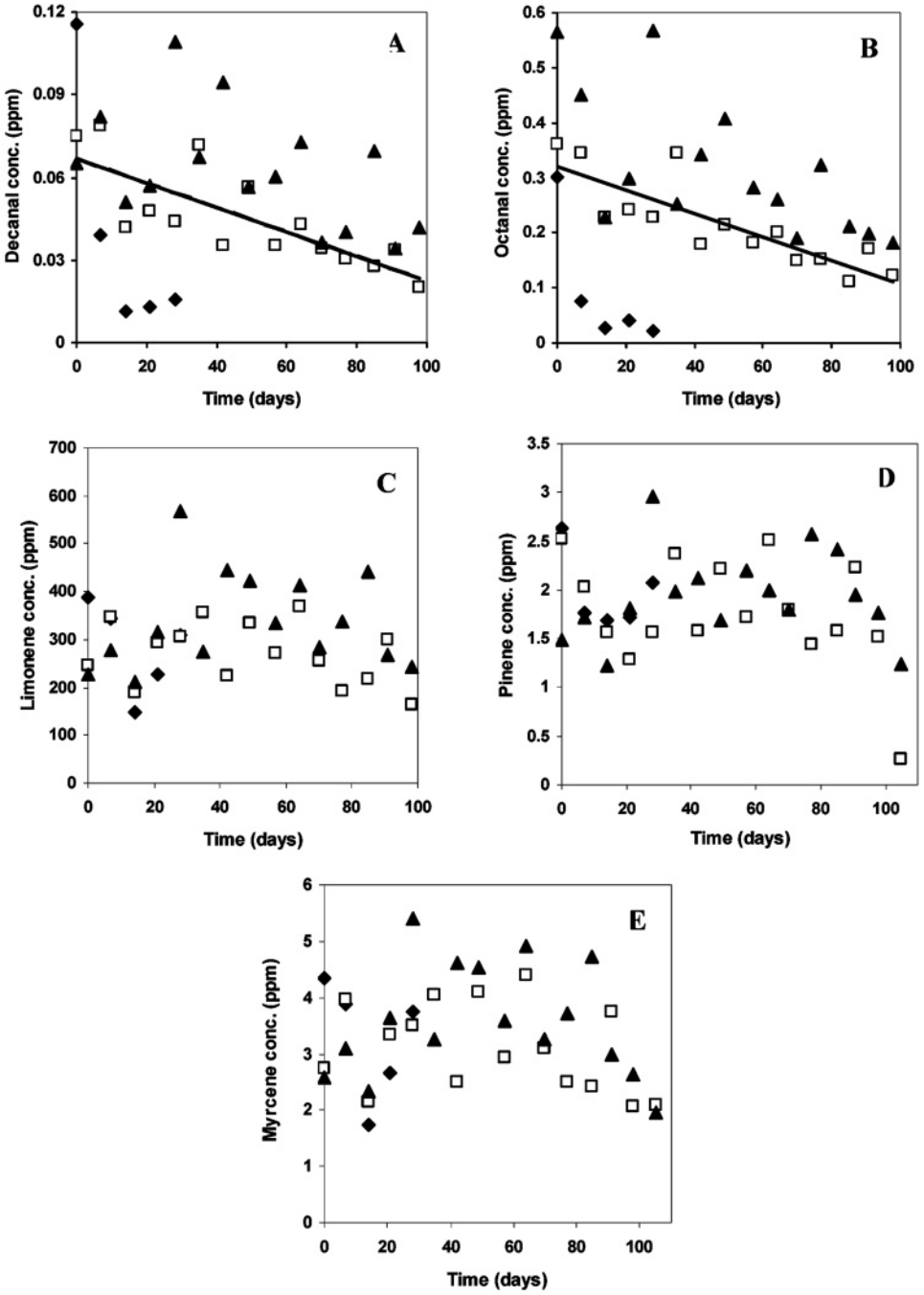

Figure 4. Flavor compounds concentration in fresh and thermally treated orange juice during storage at 4 °C: (**A**) decanal; (**B**) octanal; (**C**) limonene; (**D**) pinene; (**E**) myrcene; (◆) fresh orange juice; (▲) ohmic-heated orange juice; (□) conventionally pasteurized orange juice.

ized, and ohmic-heated orange juice. These include limonene, pinene, myrcene, octanal, and decanal. For the five flavors, higher concentrations were measured in ohmic-heated orange juice than in pasteurized juice during storage. The concentrations of limonene, myrcene, octanal, and decanal showed significantly higher values in ohmic-heated orange juice than in conventionally pasteurized juice during storage ($p < 0.05$). These results indicate better flavor retention after ohmic heating compared to conventional pasteurization, which originate from lower residence time in the ohmic heating system. Myrcene and limonene concentrations in the ohmic-heated and conventionally pasteurized orange juice did not show any detectable trend during storage. However, octanal and decanal concentrations follow an apparent linear degradation during storage in pasteurized orange juice ($r^2_{octanal} = 0.71$, $p_{octanal} < 0.0001$; $r^2_{decanal} = 0.62$, $p_{decanal} < 0.001$). It should be noted that also in the ohmic-heated juice a decrease for octanal and decanal was observed, although it was not statistically significant.

Cloud Stability. Particles in orange juice contribute to sensory characteristics, taste, color, texture, and aroma. Consumers expect to purchase juice in which the cloud is stable during storage. The visual turbidity originates from a suspension of pectin particles ranging from 0.4 to 2 μm. PE causes cloud instability in orange juice by deesterification of pectin; thus, a thermal process is applied to inactivate the enzyme. Following thermal treatments, in ohmic heating as well as in conventional pasteurization, PE activity was reduced by 90−98% compared to fresh juice. These levels did not change significantly during storage of 100 days. Apparently, no regeneration or retardation of PE activity was found for the orange juices in our study.

Table 1. Particle Size Distribution of Fresh, Pasteurized, and Ohmic-Heated Orange Juice during Storage[a]

	D[4,3] (μm)			*D*[3,2] (μm)			*D*[1,0] (μm)		
time (days)	fresh	pasteurized	ohmic	fresh	pasteurized	ohmic	fresh	pasteurized	ohmic
0	188.8 ± 103	63.4 ± 39.8	4.3 ± 0.8	16.1 ± 8.7	3.6 ± 0.8	1.4 ± 0.03	0.84 ± 0.01	0.66 ± 0.01	0.67 ± 0.01
28	641 ± 343.2			90.6 ± 8.3			2.2 ± 0.5		
49		80.1 ± 0.9	4.2 ± 0.1		5 ± 0.03	1.4 ± 0.01		0.7 ± 0.01	0. 67 ± 0.01
98		74.2 ± 0.2	3.9 ± 0.02		5 ± 0.1	1.4 ± 0.01		0.7 ± 0.01	0.66 ± 0.0.1

[a] *D*[4,3] is the equivalent volume mean diameter; *D*[3,2] is the equivalent surface area diameter; *D*[0,1] is the equivalent mean diameter. Results are presented as mean ± SD.

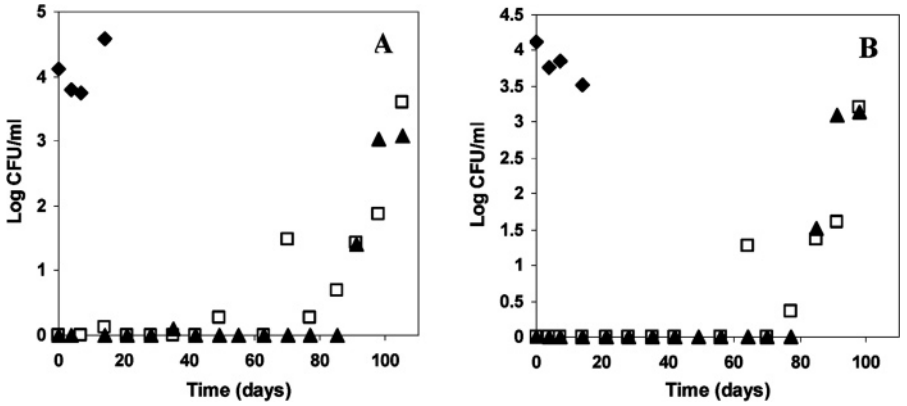

Figure 5. Microbial counts of total plate counts (**A**) and yeast and mold (**B**) in fresh (◆), ohmic-heated (▲), and conventionally pasteurized (□) orange juice during storage at 4 °C.

Moreover, no significant differences were found between PE activity levels in orange juice after either ohmic heating or conventional pasteurization ($p > 0.05$, data not shown). The findings of Sadler et al. (*23*) support these results, with no PE regeneration in pasteurized orange juice during storage at 4 °C. It can be concluded that both thermal treatments maintained low levels of PE to avoid any physical changes.

To evaluate the effect of the residual PE activity on the stability of the juice cloud, particle size analysis was performed (**Table 1**). Mean diameters, *D*[1,0], of all types of juices were <2 μm at the beginning of the experiment. It should be noted that the particle size of the fresh orange juice was significantly higher than the particle size of the pasteurized and ohmic-heated juices at day 0 ($p < 0.0001$). Indeed, during storage the levels of *D*[1,0] in the fresh juice showed significant increase ($p < 0.05$) and exceeded the upper limit of 2 μm. This level is the upper limit in the normal distribution of particle size in citrus juices, and above this value there is an indication of separation (*24*, *25*). In contrast, measurements of pasteurized and ohmic-heated juices maintained low levels of particle size during storage ($p > 0.05$). As expected, the negligible levels of PE activity during storage prevented physical changes. Furthermore, surface area mean diameters, *D*[3,2], and volume-weighted mean diameters, *D*[4,3], of conventionally pasteurized orange juice were significantly higher than the levels obtained in ohmic-heated juice during storage ($p < 0.0001$). High levels of *D*[3,2] indicate a higher potential for interaction between particles in pasteurized orange juice, thus leading more easily to aggregation. Additionally, high *D*[4,3] values indicate that the particles in the conventionally pasteurized orange juice are heavier than those in ohmic juice; thus, these particles may tend to settle more rapidly during storage.

Sensory Shelf Life. The shelf life of thermally pasteurized orange juice may end due to a number of reasons, of which we chose (1) microbial load, (2) vitamin C content, and (3) sensory. Microbial counts included total plate counts and yeast and mold counts, with the upper level of acceptable microbial load set as 10^3 CFU/mL.Using this approach, the shelf life of both ohmic-heated and conventionally pasteurized orange juice was 105 days; after 105 days, both juices showed microbial counts >10^3 CFU/mL. Apparently, the type of thermal treatment applied did not have any significant effect on shelf life regarding microbial counts (**Figure 5**). After 105 days, microscopic examinations indicated that the major microorganisms in the orange juice were mainly yeast and mold, as indeed citrus juices are most susceptible to yeast and mold spoilage due to their low pH and high contents of sugar and vitamins (*26*).

With regard to vitamin C content, orange juice should contain 60 mg of ascorbic acid per 236 mL serving to provide 100% of the U.S. Recommended Daily Allowance (U.S. RDA) requirement for vitamin C (*27*). Accordingly, the concentration of ascorbic acid in orange juice should be at least 25 mg/100 mL at the time of the expiration date for 100% vitamin C supply. The concentration of ascorbic acid in ohmic-heated and conventionally pasteurized orange juice reached this level after 79 days (**Figure 2**).

Finally, according to the Weibull−Hazard sensory shelf life determination approach, the shelf life of orange juice was defined as the time when 50% of panelists would reject the sample. Using the results from regression analysis of the cumulative-hazard plot (**Figure 6**), the shelf life of thermally treated orange juice was calculated. No cumulative-hazard plot was drawn for ohmic-heated orange juice, simply because there was no failure during shelf life. **Table 2** shows the parameters α and β obtained from the regression analysis of the cumulative-hazard plots and the subsequent measured shelf life of conventionally pasteurized orange juice.

Because the sensory testing of the ohmic-heated juice was terminated due to microbial safety considerations, we could establish only that it has a sensory shelf life of >105 days. Two repeats of the sensory shelf life experiments for the conventionally pasteurized juice result in shelf lives of 50 days. As it is

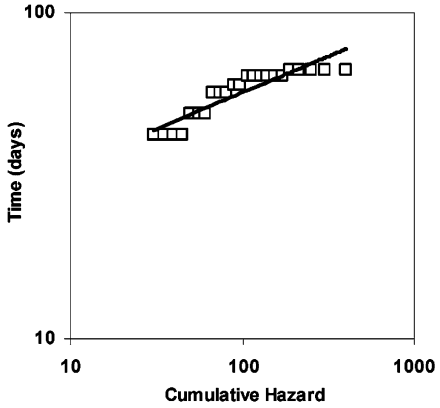

Figure 6. Example of sensory shelf life estimation for pasteurized orange juice by the Weibull–Hazard method.

Table 2. Weibull–Hazard Sensory Shelf Life Calculation for Conventionally Pasteurized Orange Juice

expt	r^2	α	β	measured shelf life (days)
A	0.83	20.423	4.492	53
B	0.652	29.307	9.2	47

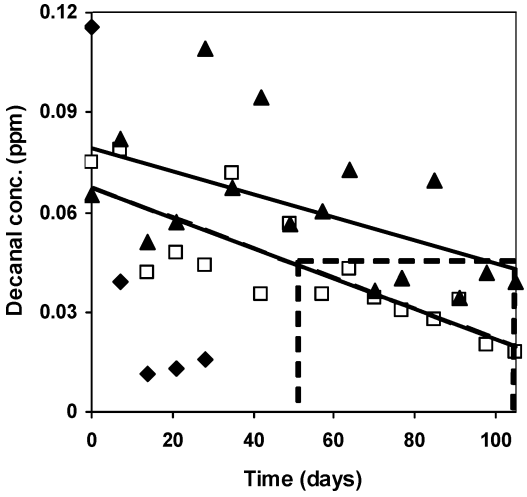

Figure 7. Decanal concentration in fresh (◆), ohmic-heated (▲), and conventionally pasteurized (□) orange juice. The dashed line shows the value of decanal at the end of shelf life of ohmic-heated orange juice, the same concentration in pasteurized juice, and, consequently, the end of shelf life of conventionally pasteurized juice.

known that a β parameter of >2 indicates a nearly normal hazard distribution, 50% rejection of the samples is a good indication of shelf life. In this study, β values in both experiments were >2. These results suggest that the sensory shelf life defines the shelf life of the conventionally treated juice.

An interesting observation is that the concentration of decanal follows the sensorial evaluation of the juice during storage. As demonstrated in **Figure 7**, at ~105 days of storage, decanal concentration in ohmic-heated juice resembles the decanal concentration in conventionally pasteurized juice at ~50 days of storage. One could therefore suggest that the sensory shelf life of pasteurized juice correlates with decanal concentration; this point, however, has yet to be studied. It should be stressed that the high decanal concentration in ohmic-heated juice stems from the high retention of aroma compounds in this juice during processing. The three key factors affecting the shelf life of thermally pasteurized and ohmic-heated orange juice, microbial counts, vitamin C content, and sensory, are summarized in **Table 3**. Under the experimental setup described in this paper, sensorial quality was the limiting factor for the shelf life of conventionally pasteurized juice, at 50 days. The ohmic-heated juice revealed superior sensorial quality, and thus its shelf life was limited by the vitamin C concentration and was 79 days.

Table 3. Shelf Life Determination of Ohmic-Heated and Conventionally Pasteurized Orange Juice According to Microbial Load, Vitamin C Content, and Sensory Evaluation

	shelf life (days)	
shelf life criterion	pasteurized OJ	ohmic-heated OJ
microorganisms	105	105
vitamin C content	79	79
sensory evaluation	50 ± 3	105

In conclusion, the shelf life of ohmic-heated orange juice was determined according to vitamin C content, which was similar to that of pasteurized juice and was 79 days. However, the prolonged sensory shelf life of ohmic-heated orange juice may influence the type of thermal treatment applied in the industry. The results of the present study suggest that a thermal treatment by continuous ohmic heating can be used to extend the sensorial shelf life of pasteurized freshly squeezed orange juice. The most interesting aspect of the continuous ohmic heating treatment is the lack of overheating due to heat transfer aspects, which result in high retention of the sensorial attributes of the fresh juice. Because by this ohmic heating system it is also possible to effectively sterilize the juice, we focus our current studies on the quality attributes of commercially sterilized juices, in particular in relation to the inactivation of thermostable sporulating bacteria.

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