Effect of PEF and heat pasteurization on the physical–chemical characteristics of blended orange and carrot juice

A. Rivas¹, D. Rodrigo¹, A. Martínez¹, G.V. Barbosa-Cánovas², M. Rodrigo¹,*

¹Instituto de Agroquímica y Tecnología de Alimentos, C.S.I.C., P.O. Box 73, 46100 Burjassot, Valencia, Spain
²Department of Biological System Engineering, Washington State University, Pullman, WA 99164-6120, USA

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Abstract

The effect of different Pulsed Electric Fields (PEF) intensities (25 kV/cm and 280 μs, P1; and 25 kV/cm and 330 μs, P2) and conventional HTST treatment (98 °C, 21 s, T) on quality characteristics (pH, °Brix, total acidity, turbidity, hydroxymethylfurfural (HMF), color, microbial flora, pectinmethylesterase (PME) activity, and sensory analysis) of blended orange and carrot juice were investigated. HMF, L* (luminosity) and C* (saturation or chrome) color parameters did not vary with any of the treatments. Total acidity and turbidity were slightly higher after HTST treatment. Sensory characteristics of the PEF-treated juice were more similar to the untreated juice than the HTST-pasteurized juice. Nevertheless, heat pasteurization (98 °C, 21 s) was more efficient in inactivating microbial flora and PME and preventing the growth of microbial flora and reactivation of PME at 2 and 12 °C for 10 weeks. However, the shelf-life of the PEF-treated juice was established as 4 weeks at 2 °C. This appears to be a reasonable shelf-life for this type of foodstuff.

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Keywords: Pulsed electric fields; Orange–carrot juice; Heat pasteurization; Quality

1. Introduction

Traditionally, most preserved juices with a pH equal to or less than 4.5 are thermally processed for a few seconds at temperatures between 60 and 100 °C (Chen, Shaw, & Parish, 1993; Jay, 1992). A great amount of energy is transferred to the food during this process, in some cases developing undesirable reactions that may produce an excessive impact and even the formation of subproducts. Nowadays, consumers look for foods with not only a long shelf-life but also high quality. To satisfy these demands, manufacturers have reacted by improving heat preservation processes, such as continuous HTST with regeneration and UHT treatments, and aseptic packaging. Despite these improvements, in some foods with characteristics or components sensitive to heat the application of even minimal thermal treatments causes losses of food quality (Espachs-Barroso, Barbosa-Cánovas, & Martin-Belloso, 2003; Hendrickx & Redd, 1995). Consequently, the food industry is looking for technologies that are less aggressive to the factors that identify the food as fresh, nutritive, and healthy. One of these technologies that is acquiring importance as an alternative to heat pasteurization is Pulsed Electric Fields (PEF).

Consumer demand for functional foods has led to the processing of derivatives of orange juice, refrigerated mixed fruit and vegetable juices. These products supply antioxidants, vitamins, and other nutritive and functional compounds. One of the most important juices is mixed orange and carrot. Besides the excellent sensory and nutritious characteristics of orange juice, the addition of carrot provides nutrients beneficial for health (Stern, 1998). When this product is heat pasteurized, it loses a great part of the characteristics...
that make it different and unattractive to the consumer. As it is a product with a high added value, processing it by a non-thermal technology such as PEF is totally justified.

There are many published works that study the effect of PEF on orange juice microorganisms and shelf-life. Inactivation of the juice microbial flora (mesophilic bacteria, molds, and yeast) and the shelf-life when stored under different conditions have been tested (Ayhan, Yeom, Zhang, & Min, 2001; Hodgins, Mittal, & Griffiths, 2002; Jia, Zhang, & Min, 1999; Min, Jin, Yeom, Min, & Zhang, 2003; Min & Zhang, 2002; Qin, Barbosa-Cánovas, Swanson, & Pedrow, 1998; Yeom, Streaker, Zhang, & Min, 2000a, b; Zhang, Sastry, & Yousef, 1996).

With regard to pectinmethylesterase (PME) enzyme inactivation, results vary depending on treatment conditions. Van Loey, Verachtert, and Hendrickx (2002) achieved only a 10% inactivation of PME dissolved in McIlvane buffer, when treated at 35 kV/cm, 1000 pulses, 1 μs width, at room temperature. When PEF treatment was combined with a moderate temperature (<65 °C), PME inactivation in orange juice increased, varying between 83% and 95% (Yeom, Chism, & Zhang, 2002; Zhang et al., 1996), respectively, depending on treatment conditions.

The evolution of certain orange juice quality factors after being treated by PEF has also been studied, and in many cases it has been compared with the evolution after thermal treatment. Yeom et al. (2000b), Ayhan et al. (2001), Min et al. (2003), and Zhang, Qiu, and Sharma (1997) studied possible color changes in samples after PEF treatment, comparing them with an untreated one. With regard to °Brix, pH, and browning index, Yeom et al. (2000b), Ayhan et al. (2001), Min and Zhang (2002), and Min et al. (2003) studied the PEF or thermal effect and their evolution with storage time.

With regard to mixed orange and carrot juice, there are studies of Lactobacillus plantarum inactivation (Rodrigo, Martinez, Harte, Barbosa-Cánovas, & Rodrigo, 2001), Escherichia coli inactivation (Rodrigo, Barbosa-Cánovas, Martinez, & Rodrigo, 2003a), PME and mesophilic, mold, and yeast flora (Rodrigo, Barbosa-Cánovas, Martinez, & Rodrigo, 2003b), and the evolution of β-carotene, β-cryptoxanthin, and 13-cis-β-carotene (Esteve, Frigola, Rodrigo, Rodrigo, & Torregrosa, 2001). As the electrical conductivity of this juice (0.45 S/m at 22 °C) is higher than that of orange juice (0.25–0.3 S/m) and due to the differences in the microbial and enzyme inactivation, and in the behavior of quality parameters compared to that of orange juice that it could cause, it is important to study the shelf-life and quality characteristics of PEF-treated orange–carrot juice and compare them with those of thermally processed juice.

2. Materials and methods

2.1. Obtaining orange and carrot juice

In the study, fresh mixed orange and carrot juice (80% orange and 20% carrot) from two different batches was used. Batch A juice was supplied by a manufacturer and batch B was obtained in the pilot plant of the Agrochemistry and Food Technology Institute, IATA (Fig. 1) The process for obtaining the batch A juice was as follows: after appropriate washing and cleaning of the fruit, the juice was extracted (FMC juice extractors with a 2 mm diameter perforated plate, FMC Corporation, Philadelphia, USA) and placed in a tank where it was mixed with carrot juice. The carrot juice for batch A was obtained after washing the vegetables first with a diluted solution of sodium hydroxide and then with drinking water. The washed vegetables were ground, the juice was sieved and mixed with the orange juice. The mixed juice was packaged in Elopak (Elopak a.s., Spikkestad, Norway) packages and frozen (−40 °C). At this temperature the biological activity stops (Whitaker, 1994).

For batch B, orange juice was extracted from the washed fruit with rotary juice extractors, the juice was sieved (0.21 mm diameter) and placed in a tank where it was mixed with carrot juice. To obtain the carrot juice for batch B, after washing and peeling the vegetables they were ground in a Model D Comminuting Machine (Fitzpatrick Company, Chicago, IL) until the smallest possible particle size (3 mm diameter) was obtained. After pressurizing (150 atm), juice was extracted from the triturate, sieved (0.21 mm diameter), mixed with the orange juice, and frozen at −40 °C.

The juice from batch A was divided into two parts. One underwent a thermal treatment similar to that given

![Fig. 1. Experimental design used in the study.](image-url)
by a manufacturer of processed refrigerated juice (T), and the other part was PEF treated (P1). The juice from batch B was given a more intense PEF treatment (P2).

2.2. PEF juice processing

An OSU-4D bench-scale continuous PEF system, designed at Ohio State University, was used to treat the samples. Six co-field treatment chambers with a diameter of 0.23 cm and gap distance of 0.293 cm were serially connected. Two cooling coils were placed before and after each pair of chambers, and submerged in a circulating refrigerated bath to control the treatment temperature. Four temperature measurements were taken, including inlet and outlet temperatures (before cooling). The temperature was monitored by using type T thermocouples fixed to the coil and connected to a data acquisition system indicator. Pulse waveform, voltage, and intensity in the treatment chambers were recorded with a digital oscilloscope (Tektronix TDS 210, Tektronix Inc., OR, USA).

The flow rate was set at 60 ml/min with a peristaltic pump. A square-wave bipolar pulse duration of 2.5 μs was selected. Treatment conditions for batch A juice were 25 kV/cm, 280 μs, 112 pulses and 767 Hz at a maximum temperature of 68 °C (P1), and for batch B juice were 25 kV/cm, 330 μs, 132 pulses and 904 Hz at a maximum temperature of 70 °C (P2). Under these conditions, the treatment was monitored to see differences among treatments, taking into account the previous results of the same authors, partially published (Rodrigo et al., 2003b). Samples were collected after each treatment time, cooled and stored until analysis. The experiments were performed in duplicate.

2.3. Thermal juice processing

The thermal treatment intensity given to the thermal-treated sample (T) (98 °C, 21 s) was fixed because it was similar to the treatment given by manufacturers of refrigerated orange juice.

An Armfield FT74P apparatus (Armfield Limited, Ringwood, England) with a plate exchanger was used to treat the samples. Juice placed in a feeding tank was rapidly heated to 98 °C. Then the juice reached the holding tube where the treatment conditions (98 °C, 21 s) were attained. After treatment, the juice was immediately cooled with cold water from a cooler (Armfield FT61), and it was packaged and stored until needed for analysis.

2.4. Packaging and storage

The treated juice was packaged avoiding air content in clean, sterile twist-off jars inside a laminar flux chamber. The closed jars were stored in two chambers (2 and 12 °C, in darkness). The analyses mentioned afterwards were carried out after 2.5, 5, 7.5, and 10 weeks for the samples stored at 2 °C and after 1, 3.5, 6, and 8.5 weeks for those stored at 12 °C.

2.5. Methods of analysis

Parameters of samples of batch A were analysed as described below, whereas for samples of batch B only microbial counts, PME activity, °Brix, total acidity and pH were analysed.

The pH was determined with a Crison model 2001 micro pH meter at 20 °C (Crison Instruments, Barcelona, Spain). The °Brix was determined by measurement of the refractive index with an Atago model RX-1000 digital refractometer at 20 °C (Atago Co. Ltd. Carneation, WA). Total acidity was determined by means of a potentiometric titration of the acidity of the juice, with a solution of 0.1 mol/l NaOH up to pH = 8.1. The results were expressed as g/100 ml with reference to citric acid (FIPJF, 1968; BOE, 1988; Kimball, 1999).

In order to measure turbidity, a sample was centrifuged (1500 rpm, 10 min), the supernatant was taken, and the absorbance at 660 nm was measured (Krop, 1974). HMF was measured spectrophotometrically at 550 nm. HMF reacts with barbituric acid and p-toluidine, forming a red-colored compound (FIPJF, 1972).

The color was determined using a Hunter Labscan II spectrophotometric colorimeter controlled by a computer that calculated color ordinates from the reflectance spectrum (Calvo & Durán, 1997). The results were expressed in accordance with the CIELAB system with reference to illuminant D65 and with a visual angle of 10°. The samples were placed in an optical glass tray, using the white plate of the colorimeter as the background (standard white plate no. LS 13681 11/86, X = 78.50, Y = 83.32, Z = 87.94). This background was used to standardize the measurements. The measurements were made in triplicate through a diaphragm 30 mm in diameter.

For the microbial counts, samples were serially diluted, plated in total count agar (PCA) for total flora counts, and in acidified potato dextrose agar (PDA) for mold and yeast counts. Plates were incubated at 30 °C for 48 h or 5 days for total flora, and molds and yeast, respectively. PME activity was measured using the method described by Kimball (1986).

For sensory taste and odor evaluation, 25 untrained volunteers were selected. The juice samples (treated juices without storage) were presented in glasses with a capacity of 100 ml. For both characteristics (odor and taste), the judges rated the preferred sample in comparison with the untreated juice control. (Freshly prepared juice, stored frozen at –40 °C and thawed).
Compusense® five release 4.6 (Compusense Inc., Guelph, ON, Canada) software was used to analyse the results.

2.6. Statistical methods

An analysis of variance was made with the results obtained for each parameter using the software Statgraphics 5.0 (Statistical Graphics Corp.).

3. Results and discussion

Table 1 shows the values of the parameters studied for the treatments given for batches A and B. The results are the average of three individual measurements.

3.1. Effects of treatment and storage on pH and °Brix

With regard to pH, both treatments (PEF and thermal pasteurization) produced a non-significant increase (P > 0.05) in the pH of the juice (Table 1). There was no variation of the pH with storage time, except for the less intensively treated sample (P1), where a decrease (P ≤ 0.05) appeared in the last weeks (8.5th week) of storage at 12 °C, owing to the beginning of microbiological spoilage of the juice (data not shown).

Various authors have studied the storage effect on the pH of fruit juices. Souci, Fachmann, and Kraut (1986), Kaanane, Kane, and Labuza (1988), and Martin, Solanes, Bota, and Sancho (1995) did not observe variations in pH during storage of pasteurized orange juice. Saldana, Stephens, and Lime (1976) also observed non-significant changes (P > 0.05) in pasteurized carrot juice. Yeom et al. (2000b) did not find changes in the pH of orange juice treated by PEF (35 kV/cm, 59 μs) and stored for 112 days at 4 and 12 °C.

In citrus juices, °Brix is used to indicate the percentage of soluble solids and is one of the most important factors for grading the quality of a citrus juice (McAllister, 1980). Microorganisms cause fruit juice spoilage by fermentation of sugars, and can therefore change the °Brix. The °Brix content of the batch A samples increased (P ≤ 0.05) with each of the treatments (Table 1). The decrease after PEF treatment of batch B samples is not statistically significant (P > 0.05), possibly owing to the fact that the sample number used in this statistical analysis is different and the sample °Brix content is higher (riper fruit). With regard to storage, no changes were observed in the samples (data not shown). Similarly, PEF-treated orange juice (35 kV/cm, 59 μs) stored for 112 days at 2 and 22 °C did not show any variation in °Brix (Ayhan et al., 2001). On the other hand, shelf-life studies on pasteurized orange juice showed a decrease in sucrose content but after 6 months of storage at 30 °C (Martin et al., 1995).

3.2. Effects of treatment and storage on total acidity

Organic acids appear in foods as a result of biochemical processes or, associated with utilization of nutrients, usually sugars, by contaminating microorganisms. The total acidity of the batch A samples increased with both treatments (PEF and heat pasteurization) (P ≤ 0.05), being slightly higher in the heat-pasteurized samples (P > 0.05) (Table 1). However, in the batch B, the P2 sample did not show variation in total acidity after PEF treatment (P > 0.05), probably owing to differences in raw materials between batches. Akinyele, Keshinro, and Akinnawo (1990), observed also an increase of the “total titrable acidity” after the orange juice pasteurization but Zarate-Rodriguez and Ortega-Rivas (2000) did not find variations in total acidity of

Table 1
Effect of the different treatments on the parameters studied for samples

<table>
<thead>
<tr>
<th>Parameters</th>
<th>BATCH A</th>
<th>BATCH B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Untreated A</td>
<td>T</td>
</tr>
<tr>
<td>°Brix</td>
<td>9.5 ± 0.1 a</td>
<td>10.4 ± 0.1 b</td>
</tr>
<tr>
<td>Total acidity (g cit.ac./100ml)</td>
<td>0.568 ± 0.012 a</td>
<td>0.626 ± 0.012 b</td>
</tr>
<tr>
<td>PH</td>
<td>3.83 ± 0.00 a</td>
<td>3.85 ± 0.02 a</td>
</tr>
<tr>
<td>Turbidity (abs. at 660 nm)</td>
<td>0.637 ± 0.100 a</td>
<td>1.310 ± 0.087 b</td>
</tr>
<tr>
<td>HMF (mg/l)</td>
<td>0.013 ± 0.001 a</td>
<td>0.013 ± 0.001 b</td>
</tr>
<tr>
<td>L*</td>
<td>62.80 ± 0.03 ab</td>
<td>62.65 ± 0.20 ab</td>
</tr>
<tr>
<td>C*</td>
<td>81.01 ± 0.09 a</td>
<td>82.30 ± 0.57 a</td>
</tr>
<tr>
<td>H*</td>
<td>69.20 ± 0.03 a</td>
<td>70.53 ± 0.25 b</td>
</tr>
<tr>
<td>Molds and yeast (cfu/ml)</td>
<td>15800 ± 3600 a</td>
<td>&lt; 1 cfu/ml b</td>
</tr>
<tr>
<td>Total Plate Counts (cfu/ml)</td>
<td>15354 ± 110 a</td>
<td>&lt; 1 cfu/ml b</td>
</tr>
</tbody>
</table>

a,b Different superscripts indicate statistically significant differences for batch A (p ≤ 0.05).
1,2 Different superscripts indicate statistically significant differences for batch B (p ≤ 0.05).

T: samples thermal pasteurized (98 °C, 21 s); P1: samples PEF treated (25 kV/cm 280 μs at a maximum temperature of 68 °C); P2: sample PEF treated (25 kV/cm 330 μs at a maximum temperature of 70 °C). The measurements were made in triplicate.
PEF-treated apple juice when compared with an untreated sample.

With regard to storage, only the less intensively treated sample (P1) showed an increase in total acidity ($P \leq 0.05$) after 7.5 weeks of storage related to the decrease found in pH, possibly owing to the onset of fermentation (data not shown).

### 3.3. Effects of treatment and storage on turbidity

The turbidity of the juice increases ($P \leq 0.05$) with the application of any of the treatments, being significantly higher ($P \leq 0.05$) in the heat-pasteurized juice (Table 1). During storage at 12°C, a significant increase in turbidity ($P \leq 0.05$) was found in sample P1 (data not shown).

### 3.4. Effects of treatment and storage on hydroxymethylfurfural

The control of furanic aldehydes is important in the evaluation of non-enzymatic browning, adulterations, heating, or incorrect storage conditions. The main decomposition product of the hydrolysis of sugars catalysed by acid is 5-(hydroxymethyl)-2-furfuraldehyde (HMF).

In this study, the HMF content was very small and did not vary with any of the treatments applied ($P > 0.05$), owing to the fact that they were both of low intensity (Table 1). During storage at 2°C, no variation was found in the content of HMF ($P > 0.05$) (data not shown). These results are similar to those found by Martin et al. (1995) in orange juice. On the other hand, an increase in HMF ($P \leq 0.05$) was found in the P1 sample at 12°C and 3.5 weeks of storage (data not shown).

### 3.5. Effects of treatment and storage on color

Non-significant changes ($P > 0.05$) were found in luminosity ($L^*$) and saturation ($C^*$) of the mixed orange and carrot juice after each of the treatments, whereas an increase in hue angle ($h^*$) (changing toward yellow) ($P \leq 0.05$) was found after each treatment (Table 1). With regard to storage at 12°C and 8.5 weeks of storage color parameters ($h^*$, $C^*$, and $L^*$) of the PEF-treated samples did not vary ($P > 0.05$) whereas $L^*$ and $h^*$ of the pasteurized samples diminish, being significantly at 12°C (Fig. 2). Zhang et al. (1997) also found a better color preservation in samples treated by PEF as compared with heat-pasteurized samples.

### 3.6. Effects of treatment and storage on pectinmethylesterase activity

One of the most important physical characteristics of orange juice and therefore of mixed orange and carrot juice is its turbidity. The main purpose of any preservation treatment in a citrus juice is to reduce PME activity, which is responsible for loss of turbidity and therefore of the commercial value of the juice. In this study, differences in residual PME activity ($P \leq 0.05$) were found which depended on the treatment intensity (Table 2). In the PEF-treated samples, the inactivation achieved was 75.6%, and 81% for treated samples P1 and P2, respectively. A 98% inactivation was found in the pasteurized samples. Only a 5% of inactivation increase was found when the treatment intensity rose from 280 μs at 68°C to 330 μs at 70°C (P1 to P2).

Rodrigo et al. (2003b) found a 79% PME inactivation in mixed orange and carrot juice (80–20%) after PEF treatment (25 kV/cm, 340 μs at 63°C). Min et al. (2003) and Yeom et al. (2002) found 88% and 90% PME inactivation after PEF treatment of orange juice. Zhang et al. (1996) achieved 95% inactivation of PME from orange juice after PEF treatment (35 kV/cm, 200 μs) with pilot plant equipment.

With regard to storage, no enzyme reactivation was found ($P > 0.05$) in any of the samples treated (Fig. 3). The reactivation observed after 1 or 2 weeks for samples coded P2 at 12°C and P1 at 2°C are not statistically significant. Yeom et al. (2000a) also found that the PEF inactivation (35 kV/cm, 49–59 μs) of PME from orange juice was irreversible when stored at 4 and 22°C for 112 days.

### 3.7. Effects of treatment and storage on microbial flora

Citrus juices are the most susceptible to yeast spoilage, owing to their low pH and high contents of sugar and vitamins (Kimball, 1999). Fermentative yeasts, usually Saccharomyces cerevisiae, are the most
Table 2
Values of pectinmethyltransferase activity (PEU) for the different untreated samples (A* and B*) and after the different treatments (T, P1 and P2)

<table>
<thead>
<tr>
<th></th>
<th>PEU0</th>
<th>PEU/PEU0</th>
</tr>
</thead>
<tbody>
<tr>
<td>A*</td>
<td>23.01</td>
<td>6.39</td>
</tr>
<tr>
<td>B*</td>
<td></td>
<td>0.020±0.004a</td>
</tr>
<tr>
<td>T</td>
<td></td>
<td>0.355±0.090d</td>
</tr>
<tr>
<td>P1</td>
<td></td>
<td>0.173±0.002b</td>
</tr>
<tr>
<td>P2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PME: pectinmethylesterase activity for untreated juice.

Temperature of 70 °C; T: thermal-treated samples (98 °C, 21 s); P1: PEF treated (25 kV/cm, 280 μs at a maximum temperature of 68 °C); P2: PEF treated (25 kV/cm, 330 μs at a maximum temperature of 70 °C); PEF: pulsed electric field.

There was a significant effect of storage temperature on the shelf-life of PEF-treated orange juice (Yeom et al., 2000a,b). Yeom et al. (2000a,b) found a shelf-life of 112 days at 4 °C for PEF-treated orange juice.

There was an effect of storage temperature on the growth of the microbial flora of the PEF-treated samples. Microorganism growth was always faster in samples stored at 12 °C (Figs. 4 and 5), so that counts were always higher in the samples stored at 12 °C. The shelf-life of the juices was established taking into account the original microbial flora. On this basis the thermally pasteurized juices had a shelf-life of at least 10 weeks, irrespective of storage temperature; whereas the PEF-treated juice (P1) had a shelf-life of 4 weeks when stored at 2 °C. Therefore, it does not seem necessary to increase the treatment intensity to P2, taking into account the increased energy consumption that it would imply.

3.8. Sensory analysis

![Graph showing sensory analysis](image)

On the basis of the average ratings given by the judges, the odor and taste of the PEF-treated samples were more accepted (higher ratings) than those of the thermally pasteurized ones (P<0.05) (Fig. 6) Dunn and Pearlman (1987) and Min et al. (2003) confirm the high organoleptic quality of PEF-treated orange juice when compared with thermally processed juice.
4. Conclusion

Because of the physical properties of the mixed orange and carrot juice, which had a high electrical conductivity (0.45 S/m at 25 °C, higher than that of orange juice), the limitations of the PEF equipment used, and the intensity of the thermal pasteurization given by manufacturers, it was impossible to reach the same microbial and enzymatic inactivation by both technologies. Nevertheless, with the PEF treatment (P1) applied with laboratory equipment, acceptable levels of enzyme and microbial inactivation were achieved, producing a juice with a shelf-life of 4 weeks at 2 °C and with sensory properties (odor and taste), color, total acidity, and turbidity more similar to that of untreated juice than the thermally pasteurized.

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References


Espachs-Barroso, A. G., Barbosa-Cánovas, G. V., & Martín-Bellosos, O. (2003). Microbial and enzymatic changes in fruit juice by high intensity pulsed electric fields. Food Reviews International, 19, 253–273.


Acknowledgment

This work was carried out with the financial support of the EU and the Spanish CICYT project 1FD97-0575-C03-01.


Min, D. B., Zhang, Q. H. (2002). Pulsed electric field processing to improve the freshness of orange and tomato juices. In *The institute of food technology meeting: Book of abstracts*.

Qin, B. L., Barbosa-Cánovas, G. V., Swanson, B. G., & Pedrow, P. D. (1998). Inactivating microorganisms using a pulsed electric field continuous treatment system. *IEEE Transactions on Industry Applications*, 34, 43–49.

Rodrigo, D., Martínez, A., Harte, F., Barbosa-Cánovas, G. V., & Rodrigo, M. (2001). Study of inactivation of *Lactobacillus plantarum* in orange-carrot juice by means of pulsed electric fields: Comparison of inactivation kinetics models. *Journal of Food Protection*, 64, 259–263.

Rodrigo, D., Barbosa-Cánovas, G. V., Martínez, A., & Rodrigo, M. (2003a). Weibull distribution function based on an empirical mathematical model for inactivation of *Escherichia coli* by pulsed electric fields. *Journal of Food Protection*, 66, 1007–1012.


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