Innovative Food Science and Emerging Technologies 17 (2013) 85–92

Contents lists available at SciVerse ScienceDirect

Innovative Food Science and Emerging Technologies

journal homepage: www.elsevier.com/locate/ifset

Effects of electric field strength and pulse rise time on physicochemical and sensory properties of apple juice by pulsed electric field

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ARTICLE INFO

Article history:
Received 2 July 2012
Accepted 25 October 2012

Editor Proof Receive Date 18 December 2012

Keywords:
Pulsed electric fields
Pulse rise time
Electric field strength
Apple juice
Enzyme
Qualities

ABSTRACT

Effects of electric field strength (0–35 kV/cm) and pulse rise time (PRT) of 2 μs and 0.2 μs during pulsed electric fields (PEF) on enzymatic activity, vitamin C, total phenols, antioxidant capacities, color and rheological characteristics of fresh apple juice were investigated. With increasing the electric field strength and PRT, the residual activity (*RA*) of polyphenoloxidase (PPO) and peroxidase (POD) decreased, almost complete inactivation of both enzymes was achieved at 35 kV/cm and 2 μs-PRT. The content of vitamin C in apple juice decreased significantly ($p<0.05$) during PEF treatment, the largest loss was 36.6% at 30 kV/cm and 2 μs-PRT. The content of total phenols was not affected by PEF with 2 μs-PRT but decreased significantly ($p<0.05$) by PEF with 0.2 μs-PRT. The antioxidant capacity of apple juice was evaluated by DPPH radical scavenging activity, ferric reducing antioxidant power (FRAP) and oxygen radical absorbance capacity (ORAC). The DPPH value was not affected by PEF, whereas FRAP and ORAC values increased with increasing the electric field strength and decreasing the PRT. PEF-treated apple juice had a significantly higher ($p<0.05$) lightness (L) and yellowness (b) than the controlled sample. The apparent viscosity and consistency index (K) of apple juice decreased while the flow behavior index (n) increased with increasing the electric field strength, and apple juice treated at 2 μs-PRT had significantly higher apparent viscosity than treated at 0.2 μs-PRT.

Industrial relevance: Apple juice is one of the most popular fruit juices, and it required strict treatment conditions to protect its quality, especially to prevent enzymatic discoloration. PEF is one promising novel non-thermal technique without compromising the flavor, taste and nutrition aspect of food. This study analyzed the effectiveness of PEF as a method of preserving qualities of apple juice, including inactivating enzymes which are crucial to quality control. Available data provided in this study will benefit the fruit juice industry.

1. Introduction

Consumers prefer a fresh-like product with little or no degradation of sensory and nutritional qualities, however, the sensory and nutritional qualities may be destroyed by heat processing, the most commonly used hurdle for inactivating microorganisms and enzymes, thereby extending product shelf life (Braddock, 1999). Consumer demand for minimally processed and fresh-like food products has led to an increased interest in innovative "non-thermal" processing technologies, which aim to achieve similar microbial and enzymatic inactivation with reduced or no application of heat (Riener, Noci, Cronin, Morgan, & Lyng, 2008).

Pulsed electric fields (PEF), a novel non-thermal technology for pasteurization or sterilization, can inactivate micro-organisms and enzymes with a small increase in temperature, providing fresh-like products with improved flavor and color characteristics as well as a high nutritive value (Aguilar-Rosas, Ballinas-Casarrubias, Nevarez-Moorillon, Martin-Belloso, & Ortega-Rivas, 2007). Many electrical parameters of PEF that influence the quality of juice have been extensively studied over the past years, including pulse profile, pulse polarity, pulse duration, pulse frequency and electric field strength (Aguilar-Rosas et al., 2007; Aguiló-Aguayo, Soliva-Fortuny, & Martin-Belloso, 2010; Evrendilek et al., 2000; Morales-de la Peña, Salvia-Trujillo, Rojas-Graü, & Martín-Belloso, 2010; Riener et al., 2008). Among these factors, electric field strength and treatment time are the most important (Castro, Barbosa–Canovas, & Swanson, 1993; Huang & Wang, 2009). Of all pulse profiles, exponential and square wave pulses are the two most used. For rectangular profile pulsed electric fields, the pulse rise time is an important waveform parameter (Chen et al., 2010). Our research team had previously reported that the pulse with shorter rise time had better effect of inactivation on *Staphylococcus aureus* incubated into apple juice and lower solution temperature increases after treatment, and the difference between the inactivation effects was more than 0.5 logs in general (Chen et al., 2010). However, no research has

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http://dx.doi.org/10.1016/j.ifset.2012.10.008

been carried out about the effects of pulse rise time on the quality attributes of fresh apple juice.

The effects of PEF on pH, soluble solids, acidity, PPO and POD activities, Vc and polyphenolics contents, and color of apple juice were most studied (Aguilar-Rosas et al., 2007; Akdemir Evrendilek et al., 2000; Charles-Rodríguez, Nevárez-Moorillón, Zhang, & Ortega-Rivas, 2007; Noci et al., 2008; Ortega-Rivas, ZÁrate-Rodríguez, & Barbosa-CÁnovas, 1998; Riener et al., 2008; Schilling et al., 2007; Walkling-Ribeiro et al., 2008). PEF treatment had no significant effect on pH (Aguilar-Rosas et al., 2007; Charles-Rodríguez et al., 2007; Ortega-Rivas et al., 1998; Schilling et al., 2007; Walkling-Ribeiro et al., 2008); acidity (Aguilar-Rosas et al., 2007; Ortega-Rivas et al., 1998; Schilling et al., 2007); soluble solids (Ortega-Rivas et al., 1998; Schilling et al., 2007; Walkling-Ribeiro et al., 2008); vitamin C content (Akdemir Evrendilek et al., 2000) and color (Akdemir Evrendilek et al., 2000; Charles-Rodríguez et al., 2007; Noci et al., 2008; Walkling-Ribeiro et al., 2008) of apple juice. Schilling et al. (2007) found the polyphenol contents and antioxidant capacities of the apple juices extracted from PEF-treated apple mash (1–5 kV/cm, n = 30 pulses) did not significantly differ from the controls. However, Aguilar-Rosas et al. (2007) found PEF treatment (35 kV/cm, and a frequency of 1200 pulses per second) caused a 14.49% reduction in phenolics content, and a significant decrease in volatile compounds in apple juice. Besides, Riener et al. (2008) obtained the highest level of decrease in the enzymatic activity of 71% and 68%, for PPO and POD, respectively by using a combination of preheating to 50 °C, and a PEF treatment time of 100 μs at 40 kV/cm, and the kinetic data for the inactivation of both enzymes could be well described using a 1st-order model. However, little research has been carried out about the effect of PEF processing on rheological behavior and antioxidant capacities of apple juice.

This study investigated the effect of pulse rise time on the quality attributes of apple juice since not many reports on this aspect appear in the literature. The combination of pulse rise time and electric field strength, which was a most important factor in PEF processing, was also taken into consideration. For quality attributes of apple juice, enzymatic activity, vitamin C, total phenols, color, especially antioxidant capacities, expressed by DPPH, FRAP, ORAC values, and rheological characteristics were investigated.

2. Material and methods

2.1. Preparation of fresh apple juice

Apples (*Malus domestica* Fuji) were purchased from the local market in Beijing (China) and stored in a cold warehouse at an average temperature of 5 °C overnight before use. The apples were washed, sliced and squeezed by a juice extractor (JYL-B060, Joyoung Co., Ltd, China) and then filtered with four layers of cheesecloth. To prevent the browning of the juice, 1‰ (m/v) of L-ascorbic acid (Aoboxing Biotechnical Co., Beijing, China) was added to the freshly squeezed juice. Because the valves and pipelines in the PEF system might clog if the juice was very rich in pulp, all the juice was filtered again with 8 layers of cheesecloth after deaerated. The juice was later stored at the cold warehouse and treated by PEF within 2 h. The final juice had a pH of 3.92, conductivity of 2.00 mS/cm, total souble solid of 8.71°Brix.

2.2. PEF system

A newly developed THU-PEF3 (Developed by Graduate School at Shenzhen, Tsinghua University) pulsed electric field system was used for the treatment of apple juice. The main parameters used in this study were square mono-polar pulses of a 5 μs pulse duration and 16 Hz pulse frequency. The pulse voltage applied to the sample was 10, 12, and 14 kV and the corresponding electric field strength was 25, 30, and 35 kV/cm, respectively. Two co-field flow PEF treatment chambers with a gap distance of 4 mm and an inner diameter of 4 mm were used, and the volume of the treatment chamber was 0.05 mL. Stainless steel (316L) was used as electrode material. The peak voltage output was measured at PEF treatment chambers with a high voltage probe P6015A coupled with a digital oscilloscope TDS1001B (Tektronix Inc). Sample temperature was monitored by a thermo-couple sat in the outlet ends of the treatment chambers. A pulse optimizing network was added to guarantee the pulse rise time in the range of 0–0.2 μs. As shown in Fig. 1, the pulse rise time was close to 2 μs without pulse optimizing network and was approximately 0.2 μs with the network.

2.3. PEF processing

The apple juice was pumped into the treatment chamber with a flow rate of 6.4 mL/min, and the inlet PEF temperature of the apple juice was 16–21 °C. Then the apple juice was treated at electric field strength of 0, 25, 30, and 35 kV/cm for 75 μs with PRT of 2 μs or 0.2 μs. The first 45 mL of treated sample was discarded to ensure stationary treatment conditions. After collection for 5 min, 32 mL of processed apple juice at the outlet of the treatment systems were collected in tube, which was set in an ice bath. Then the juice was filled into polyethylene bags, heat-sealed under vacuum, then immediately stored at 4 °C, detected within 2 h. The samples were considered as the control before PEF treatment. Before and after each experiment, the PEF system was rinsed by deionized water for 20 min. All treatments were conducted in quadruplicate. Under these specific PEF conditions, the temperature of samples after PEF treatment was 21–42 °C.

2.4. Energy density

The energy density dissipated in the food sample is an important parameter during PEF processing. It depends on lots of factors, such as

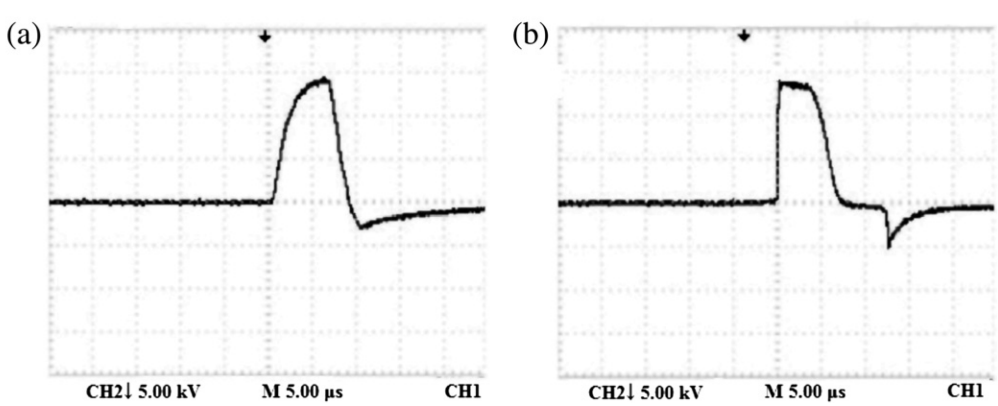

Fig. 1. Waveform of different pulse rise time. (a) 2 μs pulse rise time and (b) 0.2 μs pulse rise time.