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A comparative assessment of long-term storage stability and quality attributes of orange juice in response to pulsed electric fields and heat treatments

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ABSTRACT

Processing of orange juice by pulsed electric fields (PEF) and heat treatments was carried out to determine the quality variables during storage of 180 days at 4 °C. Depending on the magnitude of applied electric field strength (13.82–25.26 kV cm^{-1}), energy (10.89–51.32 J), in comparison with heat treatment (90 °C for 10 and 20 s); significant changes in pH, titration acidity, total dry matter, and browning index were found during the storage period. With no significant change in shelf-life period, the PEF processing better preserved orange juice quality than did the heat processing. Ascorbic acid content peaked with PEF-treated orange juice under the electric field strength of 17 kV cm^{-1}, the treatment time of 1034 μs, and the energy of 17.37 J through which no significant degradation occurred during the storage with the longest half-life (1112 days). Although ascorbic acid retention of the most of the PEF processed samples was higher than that of the heat processed ones; samples processed by 10.89, 12.70 and 29.57 J energies resulted in lower ascorbic acid content than did the heat processing (90 °C for 20 s). Except for the samples treated by 43.99 and 51.32 J energies on 180th day, the PEF processing led to no hydroxyl methyl furfural formation during and at the end of the storage, unlike the heat treatment.

1. Introduction

Citrus juices have gained a great popularity accounting for more than 50% of juices available in international commerce (Tiwari et al., 2009). Orange juice is the most predominant product processed by the beverage industry and consumed worldwide owing to its high ascorbic acid content, carotenoids and phenolic compounds, and its high nutritional value and desirable sensorial characteristics (Agcam et al., 2014a; Katsaros et al., 2010; Plaza et al., 2006, 2011; Vervoort et al., 2011). Epidemiological studies have suggested that increased consumption of these compounds has antioxidant effects and decreases the risk of developing several types of cancer, neurological, and cardiovascular diseases (Nishino, 2009; Willett, 2002). Ascorbic acid as the most important water-soluble antioxidant can directly scavenge superoxide radical, singlet oxygen, hydrogen peroxide, and hydroxyl radical (Klimczak et al., 2007). Gardner et al. (2000) reported that 66% of the potential antioxidant capacity could be attributed to ascorbic acid. Ascorbic acid level, or ascorbic acid degradation is a reliable indicator of nutritional value, and quality deterioration of processed orange juice, with a limited shelf-life as

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it decreases depending on storage and processing conditions (Klimczak et al., 2007; Manso et al., 2001; Polydera et al., 2003).

Non-enzymatic browning is the first visible quality defect to be detected during processing and storage and significantly influences the commercial value of citrus products. In citrus juices, browning may result from reactions of sugars, amino acids, and ascorbic acid (Fustier et al., 2011; Lee and Coates, 1999; Meydav et al., 1977; Valdramidis et al., 2010). Ascorbic acid degradation can lead to non-enzymatic browning of citrus juices which in turn causes significant adverse impacts on their flavor and color during storage, consumer acceptance and shelf-life with the formation of unstable intermediate compounds such as furfurals (Nagy, 1980; Villamiel et al., 1998; Zulueta et al., 2010).

Heat processing inactivates both microorganisms and enzymes of commercial orange juices, and thus, is the most common method used to extend their shelf-life (Chen and Wu, 1998; Elez-Martinez et al., 2006). However, heat processing has been reported to often lead to adverse impacts on sensory and nutritional quality of orange juice (Agcam et al., 2014a; Lee and Coates, 2003; Plaza et al., 2011; Polydera et al., 2004; Vervoort et al., 2011). Pulsed electric fields (PEF) as one of the non-thermal preservation technologies has emerged in response to an increased consumer demand for safe foods with a fresh-like quality and longer shelf-life (Walkling-Ribeiro et al., 2009). PEF was demonstrated to be an alternative or complementary to heat pasteurization in the field of pumpable liquid foods given their better performance for the inactivation of microorganisms and enzymes, and the preservation of organoleptic characteristics (Cortes et al., 2008b; Evrendilek et al., 2004; Yeom et al., 2000a).

Several studies were conducted to determine the short-term storage stability of PEF-treated orange juice in comparison to conventional heat pasteurization (Cortes et al., 2008a,b; Elez-Martinez et al., 2006; Plaza et al., 2006, 2011; Timmermans et al., 2011; Torregrosa et al., 2006; Vervoort et al., 2011; Yeom et al., 2000a,b). PEF was found very effective to inactivate pectin methyl esterase (PME) with no PME recovery during storage (Agcam et al., 2014b; Yeom et al., 2000a,b). PEF was also reported to successfully inactivate endogenous microflora, and foodborne pathogens (Gurtler et al., 2010; McDonald et al., 2000; Rivas et al., 2006). However, there exist only a few comparative studies about the determination of PEF- versus heat-induced quality changes in orange juice during a long-term storage. Therefore, the objectives of the present study were to comparatively quantify effects of PEF versus heat treatments on storage stability and critical quality variables of orange juice for 180 days at 4 °C estimating degradation kinetics of ascorbic acid, and formation kinetics of hydroxyl methyl furfural (HMF).

2. Materials and methods

2.1. *Orange juice*

Kozan variety oranges grown in the Cukurova region (Turkey) were washed, peeled, cut into two halves, and pressed using a bench-scale automatic orange squeezing machine (CANCAN, Turkey). Orange juice was passed through 1-mm stainless steel sieves to remove seeds and coarse pulps. Juice was immediately processed using PEF or heat pasteurization units.

2.2. *PEF treatments*

A laboratory-scale PEF OSU-4A system (Evrendilek et al., 2004) was used for PEF treatments. PEF generator provided square wave bipolar pulses and was equipped with six co-field flow chambers with a diameter of 0.23 cm and a gap distance of 0.292 cm. After preliminary experiments conducted to determine the electric field strength, treatment time, frequency, and pulse width based on physical properties of orange juice such as pH, °Brix, viscosity, and conductivity, the following PEF processing parameters were used to process orange juice samples: E1 (13.82 kV cm^{-1} electric field strength, 1033.9 μs treatment time, 10.89 J energy), E2 (13.82 kV cm^{-1} electric field strength, 1206.2 μs treatment time, 12.7 J energy), E3 (17.06 kV cm^{-1} electric field strength, 1033.9 μs treatment time, 17.37 J energy), E4 (17.06 kV cm^{-1} electric field strength, 1206.2 μs treatment time, 20.26 J energy), E5 (21.50 kV cm^{-1} electric field strength, 1033.9 μs treatment time, 29.57 J energy), E6 (21.50 kV cm^{-1} electric field strength, 1206.2 μs treatment time, 34.50 J energy), E7 (25.26 kV cm^{-1} electric field strength, 1033.9 μs treatment time, 43.99 J energy), and E8 (25.26 kV cm^{-1} electric field strength, 1206.2 μs treatment time, 51.32 J energy). The flow rate, frequency and pulse width of the PEF processing were 0.633 mL s^{-1}, 500 s^{-1}, and 3 μs, respectively (Table 1). Treatment temperature was measured during processing before and after each pair of the PEF treatment chamber using K type dual channel digital thermocouples (Fisher Scientific, Pittsburgh, PA, USA). The PEF-processing was conducted at 35 °C (water bath temperature); however, processing temperature increased up to 58.2 °C with the increased electric field strength.

2.3. *Heat pasteurization treatment*

A bench-scale system designed by Agcam et al. (2014b) in the Department of Food Engineering of Cukurova University (Adana, Turkey) was used for heat pasteurization. As a result of the preliminary experiments, the two heat pasteurization treatments at 90 °C for both 10 s (H1) and 20 s (H2) were applied.

2.4. *Measurements of quality attributes of orange juice*

Titration acidity and dry matter of the juice samples were carried out according to AOAC (1990). Total dry matter and pH of orange juices were analyzed using a lab scale vacuum dryer (Blue Pard, China) at 65 °C and a pH-meter (WTW, Germany) at room temperature (~25 °C), respectively. Five mL of orange juices were mixed with 5 mL ethyl alcohol (95%) in teflon tubes, and then centrifuged (4000 rpm, 10 min, at 4 °C) for the determination of browning index. The supernatant was passed through a 0.45-μm teflon membrane filter, and the absorbance of the supernatant was measured at 420 nm with a spectrophotometer (Perkin Elmer Lambda 25-UV/vis, USA) (Meydav et al., 1977).

Ascorbic acid content was determined using a HPLC method, and an extraction procedure described by Lee and Coates (1999). Five mL of the orange juice samples were transferred into teflon centrifuge tubes containing 5 mL of 2.5% meta phosphoric acid. A 0.5-mL aliquot of the supernatant was pipetted into a glass tube, and its total volume was completed to 10 mL with 2.5% metaphosphoric acid. The tube was mixed with vortex at a high speed, and the mixture was filtered using a 0.45-μm teflon filter (Millipore, Munich, Germany). HPLC (Shimadzu LC-20AT, Japan) system used in the present study