Journal of Food Engineering 89 (2008) 210–216

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Modeling changes in health-related compounds of tomato juice treated by high-intensity pulsed electric fields

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ARTICLE INFO

Article history:
Received 17 January 2008
Received in revised form 8 April 2008
Accepted 19 April 2008
Available online 28 April 2008

Keywords:
Modeling
High-intensity pulsed electric fields
Tomato juice
Health-related compounds
Antioxidant capacity

ABSTRACT

Changes in some health-related compounds (lycopene and vitamin C) and antioxidant capacity of tomato juice treated by high-intensity pulsed electric fields (HIPEF) were modeled as a function of the electric field strength and treatment time. Samples were subjected to electric field strengths from 20 to 35 kV/cm for up to 2000 μs using bipolar 1-μs pulses at 250 Hz. Weibull kinetic models predicted vitamin C and antioxidant capacity retention of HIPEF-treated tomato juice with good accuracy ($R^2_{adj} \geqslant 0.836$; $A_f = 1.001–1.010$). A model used to describe moisture sorption processes was the most accurate for describing lycopene changes through the HIPEF treatment time. The combined effect of treatment time and electric field strength on health-related compounds of tomato juice were successfully predicted ($R^2_{adj} > 0.948$; $A_f = 1.016–1.017$) through secondary expressions. Information from this study would be useful in determining optimal HIPEF-conditions to produce tomato juices with a high retention of bioactive compounds.

1. Introduction

Regular intake of tomatoes and tomato based products has been associated with lower incidence of various forms of cancer, in particular prostate cancer, and heart diseases (Arab and Steck, 2000). This beneficial effect is believed to be due, at least partially, to the action of antioxidant compounds, which reduce oxidative damage in the body. However, the nutritional value of tomato products depends on several factors such as processing and storage conditions (Willcox et al., 2003). Consumers demand high quality nutritious foods with fresh flavor, texture and color as well as with minimal or no addition of chemical preservatives (Bull et al., 2004). Consequently, emerging technologies for food processing and preservation, such as high-intensity pulsed electric fields (HIPEF), are being investigated (Deliza et al., 2003). HIPEF processing, as a non-thermal technology, has been shown to effectively inactivate microorganisms in tomato juice, thus leading to microbial inactivation levels similar to those achieved with heat pasteurization (Min et al., 2003). In addition, HIPEF treatments can achieve high rates of tomato juice peroxidase (POD), pectin methylesterase (PME) and polygalacturonase (PG) inactivation (Aguiló-Aguayo et al., 2007, 2008). Several authors have studied the evolution of quality parameters in tomato juice after HIPEF treatments and promising results have been obtained regarding the maintenance of health-related compounds and color attributes compared to heat treatments (Min et al., 2003; Odriozola-Serrano et al., 2008). Process parameters such as electric field strength and treatment time are important variables to be controlled in order to optimize the inactivation of microorganisms (Elez-Martínez et al., 2004, 2005) and enzymes (Giner et al., 2000; Elez-Martínez et al., 2006) by HIPEF. In addition, there are several works studying the effect of HIPEF treatment parameters on health-related compounds in juices. For instance, Cortés et al. (2006) reported that electric field strength and treatment time had a significant effect on HIPEF-treated orange juice carotenoids. In this way, Elez-Martínez and Martín-Belloso (2007) concluded that vitamin C retention and the antioxidant capacity in orange juice and "gazpacho" cold vegetable soup mostly depended on electric field strength and treatment time. On the other hand, several models have been used to describe the microbial destruction (Rodrigo et al., 2001; Elez-Martínez et al., 2004) and enzymatic inactivation (Giner et al., 2005; Elez-Martínez et al., 2006) as a function of the HIPEF critical parameters. Although retention of health-related compounds can be a limiting factor when defining process conditions, little information is available on modeling the content of antioxidant compounds as affected by HIPEF treatment parameters (Bendicho et al., 2002; Torregrosa et al., 2006). Therefore, the aim of this work was to propose mathematical models that properly relate changes in health-related compounds, namely lycopene and vitamin C, and antioxidant capacity of tomato juice to electric field strength and HIPEF treatment time.

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doi:10.1016/j.jfoodeng.2008.04.019

2. Materials and methods

2.1. Tomato juices

Tomatoes (*Lycopersium esculentum* Mill. cultivar Bodar) at commercial maturity were bought from a local supermarket and kept at 4 °C before being processed. The fruits were chopped, crushed and then filtered through a 2-mm diameter steel sieve. Electric conductivity (Testo 240 conductivimeter; Testo GmBh & Co, Lenzkirch, germany), pH (crison 2001 pH-meter; Crison Instruments SA, Alella, Barcelona, Spain), soluble solids content (Atago RX-1000 refractometer; Atago Company Ltd., Japan) and color (Macbeth-Kollmorgen Institute Corp., Newburg, NY) of tomato juice were determined. The physico-chemical characteristics of just filtered tomato juice were: soluble solids = 4.1 ± 0.2°Brix, pH 4.32 ± 0.33, electric conductivity = 0.63 ± 0.21 S/m, and color L^* = 22.21 ± 0.53, a^* = 6.88 ± 0.33 and b^* = 5.14 ± 0.23.

2.2. Pulsed electric fields equipment

HIPEF treatments were carried out in a continuous flow bench scale system (OSU-4F, Ohio State University, Columbus, OH, USA). The treatment system consists of eight collinear chambers in series, each one with two stainless steel electrodes separated by a gap of 0.29 cm, thus defining a treatment volume of 0.012 cm^3. The flow rate of the process was adjusted to 60 mL/min and controlled with a variable speed pump (model 752210-25, Cole Palmer Instrument Company, Vermon Hills, IL, USA). Treated tomato juice was passed through a cooling coil was connected between each pair of chambers and submerged in an ice–water shaking bath. Thermocouples were attached to the surface of the stainless steel coils, 2.5 cm away from the HIPEF zones along the flow direction. The thermocouples were connected to temperature readers and isolated from the atmosphere with an insulation tape. The temperatures of the inlet and outlet of each pair of chambers were recorded every 0.1 s during HIPEF treatment and the samples never exceeded 40 °C. Samples of tomato juice were subjected to field strengths of 20, 25, 30 and 35 kV/cm during 100, 300, 600, 1000, 1500 and 2000 μs, using 1-μs square-wave bipolar pulses at 250 Hz. Treatment conditions were selected according to a previous study (Odriozola-Serrano et al., 2007a).

2.3. Bioactive compounds

2.3.1. Lycopene

Lycopene concentration in tomato juice was measured spectrophotometrically (CECIL CE 2021; Cecil Instruments Ltd., Cambridge, UK) following the method proposed by Davis et al. (2003). About 0.6 g of tomato juice was weighted and added to 5 mL of 0.05% (w/v) butylated hydroxytoluene in acetone, 5 mL of 95% USP grade methanol, and 10 mL of hexane. The homogenate was centrifuged at 320*g* for 15 min at 4 °C. Then, 3 mL of distilled water were added to each vial and the samples were shaken for 5 min at 4 °C. Afterwards, the vials were left at room temperature for 5 min to allow separation. The absorbance of the upper, hexane layer was measured in a 1-cm pathlength quartz cuvette at 503 nm blanked with hexane. The lycopene content of each sample was estimated according to Eq. (1):

$$\text{lycopene}(\text{mg/kg}) = \frac{A_{503} \times MW \times DF \times 1000}{\varepsilon \times L} \quad (1)$$

where MW is the molecular weight of lycopene (536.9 g/mol), DF is the dilution factor, L is the pathlength in cm and ε is the molar extinction coefficient for lycopene (172,000 L/mol cm).

Results were expressed as lycopene retention compared to the untreated sample.

2.3.2. Vitamin C

Vitamin C content of tomato juice was analyzed by HPLC. The extraction procedure was based on a method validated by Odriozola-Serrano et al. (2007b). A sample of 25 mL of tomato juice was mixed with 25 mL of a solution containing 45 g/L metaphosphoric acid and 7.2 g/L DL–1,4-dithiotreitol. The homogenate was centrifuged at 22,100*g* for 15 min at 4 °C (Centrifuge Avanti™ J-25, Beckman Instruments Inc., Fullerton, CA, USA). The supernatant was vacuum-filtered through Whatman No. 1 paper. Then, the samples were filtered with a Millipore 0.45 μm membrane. An aliquot of 20 μL was injected into the HPLC system consisting of a reverse-phase C18 Spherisorb® ODS2 (5 μm) stainless steel column (4.6 mm × 250 cm) and a 486 Absorbance Detector (Waters, Milford, MA). A 0.01% solution of sulphuric acid adjusted to pH 2.6 was used as eluent. The flow was isocratic at a rate of 1 mL/min at room temperature. Detection was performed at 245 nm. Identification of the ascorbic acid was carried out comparing the retention time and UV–visible absorption spectrum of the juice samples with those of the standards. Results were expressed as vitamin C retention related to the untreated sample.

2.4. Antioxidant capacity

The antioxidant capacity of tomato juice was studied through the evaluation of free radical-scavenging effect on 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical, according to the method described by Odriozola-Serrano et al. (2007a). Samples of tomato juice were centrifuged at 6000*g* for 15 min at 4 °C (Centrifuge Medigifer; Select, Barcelona, Spain) and aliquots of 0.01 mL of the supernatant were mixed with 3.9 mL of methanolic DPPH (0.025 g/L) and 0.090 mL of distilled water. The homogenate was shaken vigorously and kept in darkness for 30 min. Absorption of the samples was measured with a spectrophotometer at 515 nm against a blank of methanol without DPPH. Results were expressed as antioxidant capacity retention related to the untreated sample.

2.5. Data analysis

Each processing condition was assayed in duplicate and two replicate analyses were carried out in order to obtain the mean value. Several models such as first-order, first-order fractional conversion, Weibull distribution, Fermi and Hülsheger model have been used to describe the microbial destruction and enzymatic inactivation as a function of the HIPEF critical parameters. These different models were fitted to the experimental data and it was found that first-order model (Eq. (2)), Weibull distribution function (Eq. (3)) and a model proposed by Peleg (Eq. (5)), best relate the changes in antioxidant properties of tomato juices to HIPEF processing parameters.

First-order kinetics (Eq. (2)) are commonly used to fit the variation of health-related compounds in juices and nectars as a function of treatment time for heat processing (Vieira et al., 2000; Vikram et al., 2005; Wang and Xu, 2007). Bendicho et al. (2002) proposed a first-order model to describe the vitamin C changes in milk as affected by HIPEF treatment time.

$$RC = RC_0 \cdot \exp(-k_1 \cdot t) \quad (2)$$

where RC (%) is the relative content of health-related compounds or relative antioxidant capacity, RC_0 (%) is the intercept of the curve, k_1 is the first-order kinetic constant (μs^{-1}) and t is the treatment time (μs).

Weibull distribution Eq. (3) has been used to describe destruction of microorganisms (Rodrigo et al., 2001) and enzyme inactivation (Rodrigo et al., 2003; Giner et al., 2005; Soliva-Fortuny et al., 2006) under HIPEF. The use of Weibull distribution function to