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Comparative study of ohmic vacuum, ohmic, and conventional-vacuum heating methods on the quality of tomato concentrate

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ABSTRACT

In the present research, tomato juice was concentrated via Ohmic heating with two modes of operation, namely atmospheric condition (OHAC) and vacuum condition (OHVC), and conventional vacuum heating (CVH) as the control mode. The effect of heating conditions on the quality of tomato concentration (lycopene, turbidity, pH and acidity) and electrical conductivity were evaluated. The OHVC reduced the concentration time in the range of 10–30%, compared with the OHAC. The comparison of the mean value of the heating rate indicated that the vacuum application reduced the heating rate by 0.8%. The electrical conductivity of OHAC changed from 0.68 S/m at initiate point to 1.25 S/m at the boiling point then decreased to 1.05 S/m at the end of the process, the corresponding values for OHVC was 0.7, 1.13 and 1.11 S/m. The mean percentage change of pH, acidity, lycopene, and turbidity for OHVC were 0.47, 24.03, 7.99, and −30.77 respectively which were lower to the corresponding value for OHAC and CVH. It appears that the application of vacuum condition in the ohmic heating treatment of tomato juice can preserve juice quality.

Industrial relevance: Due to the high energy consumption of heating in the conventional processing methods, energy efficient systems are demanded for thermal concentration of juices. Ohmic heating is an emerging technology and a very promising in food industries. Comparing with conventional heating processes, ohmic heating can save energy and provide a rapid and uniform heating of pumpable food, resulting a product with a higher quality. The results showed that vacuum coupled with ohmic heating had a significant effect on quality. One of the keys to reducing the thermal damage to products during manufacture is the shortening of the heating time and reducing the boiling point, ohmic-vacuum heating required a lower time and boil at lower temperature, thereby is more advisable for thermal processing from the point of view of energy saving and quality aspects.

1. Introduction

Tomato belongs to the family of *Solanaceae*, containing different types of vitamins. A wide range of processed tomato products such as juice, ketchup, paste, purée, sauce are available all over the world (Gould, 1992b, chap. 26; Heuvelink, 2005). The thermal treatment is the most common processing method employed for producing tomato products. In this regard, the final product experiences a temperature gradient during processing. Conventional food heating methods require that heat energy be generated externally and transferred to the food material by conduction, convection or radiation. For products containing particulates, especially large ones, conventional heating methods require excessive heating process, thereby degrading the outer portion of particulates. Accordingly, to develop new technologies for thermal food treatment is of great industrial and scientific interest.

Ohmic heating, also called electrical resistance heating, is a process where an alternating current is passed through food materials resulting in heat generation(Boldaji, Borghei, Beheshti, & Hosseini, 2015; Ramaswamy, Marcotte, Sastry, & Abdelrahim, 2014). The advantages of ohmic heating are 1) uniform and volumetric heating of pumpable food even with a mixture of solid particles, 2) rapid heating, hence a short time processing can be designed (high temperature-short time HTST), or even with ultra-high temperature (UHT), 3) high efficiency, 4) low maintenance costs due to omitted moving parts, 5) potential application to different processes of food materials such as blanching, thawing, drying, concentration, pasteurization and 6) preservation of the nutritional values of food. (Anderson, 2008; Castro, Teixeira, Salengke, Sastry, & Vicente, 2004; Darvishi, Hosainpour, Nargesi, & Fadavi, 2015; Knirsch, Alves dos Santos, Martins, & Vessoni Penna, 2010; Sakr & Liu, 2014; Zhu, Zareifard, Chen, Marcotte, & Grabowski,

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2010). Types of ohmic heating are classified based on the movement of liquid: Parallel plate, parallel rod, collinear, staggered rod, and batch arrangement (Sakr & Liu, 2014). The disadvantage of this method is for materials with a low electrical conductivity that causes a longer time for processing (Zareifard, Ramaswamy, Trigui, & Marcotte, 2003) or mixture with a different electrical conductivity where current can bypass materials such as fat globules with low electrical conductivity (Anderson, 2008).

Vacuum application is a widespread technique, accompanied to a variety of food processing methods (evaporation, distillation, Pervaporation, crystallization, evaporative cooling, drying) to prevent oxidation reactions (such as lipid oxidation, loss of certain vitamins, oxidative browning, loss of pigments, etc.), to increase the rate of heat transfer, to prevent product overheating and avoiding excessive heat damage to the product that are particularly prone to thermal damage (Berk, 2008). Thus, ohmic heating combined with vacuum could have different advantages. The aim of the research was to analyze the effect of ohmic heating under vacuum and atmospheric conditions on certain physicochemical parameters (pH, lycopene, acidity, and turbidity), electrical conductivity, processing time and heating rates and then the results compared with conventional-vacuum heating as the control sample.

2. Material and methods

2.1. Sample preparation

Fresh tomatoes were collected two times from a local farm (in Pakdasht, Iran), first for all tests under atmosphere condition on June 23, 2016, second for vacuum condition and control mode on July 19, 2016. They were kept in the refrigerator at 7 °C during the experiment. The mature and undamaged tomatoes were chosen prior to each test by visual observation of color. After washing with tap water, the tomatoes were crushed and heated indirectly by hot water for peeling (Gould, 1992a, chap. 9). Next, the tomato juice was extracted through the use of a domestic juicer (Parskhazar, Iran). The average moisture content of the tomato juice was 24.8 (kg water/kg dry matter), as determined by the oven at 105 ± 1 °C after 24 h and with five replicates.

2.2. Experimental setup and procedures

Ohmic heating, ohmic-vacuum heating, and conventional-vacuum heating were used in this study.

2.2.1. Ohmic and ohmic vacuum heater

A schematic diagram of the experimental setup (ohmic and ohmic-vacuum) is illustrated in Fig. 1. The ohmic vacuum heater unit consisted of a PTFE cell with two stainless steel electrodes (height, width, thickness were 70, 34, 2 mm, respectively) and a glass dome for the vacuum mode, a power control unit (Toyo MST-5kVA, 0–300 V, 50 Hz, China), a power analyzer (Lutron DW-6090, Taiwan), a coated type-K thermocouple, a buffer tank to damp the pulsation of pump operation, a ring vacuum pump, a vacuum gage, an inverter (SV015IC5-1F, South Korea) to control the vacuum pump, digital balance(A&D GF600, Japan) with an accuracy of ± 0.01 g for mass determination and a personal computer.

The digital balance was positioned under the cell for mass determination. The time interval for the temperature, sample mass, and the current and voltage measurement was 5 s.

2.2.2. Conventional-vacuum heater

Conventional concentration process was performed using a laboratory hot plate (IKA; RH basic 2, Germany) that placed under Erlenmeyer flask vacuum then both devices were put on the digital balance (A&D GF600, Japan). The Erlenmeyer flask vacuum was replaced by ohmic cell and connected to vacuum pump through buffer tank (Fig. 1). In order to have enough materials, a sample of 100 g was concentrated to obtain the same moisture content (~18 dry basis) as ohmic process.

2.3. Quality aspects

The tomato sample (30 gr ± 0.1) was poured between the two electrodes by assuring good contact between the electrodes and the sample. The thermocouple was placed at the geometrical center of the cell. After the ohmic-vacuum system was sealed and the vacuum pressure was adjusted to 40 kPa. Any change in each physicochemical property (pH, acidity, lycopene, and turbidity) was reported according to the Eq. (1) when the tomato juice was ohmically concentrated from the initial moisture content of 24.76 ± 0.09 (dry basis) to concentrated product with moisture content of 18.83 ± 0.08 (dry basis) for three different voltages of 40, 50, and 60 V or voltage gradients of 10.5, 13.2, and 15.8 V/cm with 50 Hz.

$$\Delta P(\%) = (|P_f - P_i|/P_i) \times 100 \tag{1}$$

Where ΔP is the change percentage in the value of the property (%), and P_f and P_i are the final and initial values of each property respectively. The ΔP in the Figures indicates the mean value of three repetitions. pH was measured using a digital pH meter (Hanna Hi 207, Italy). Total titratable acidity was analyzed by titrating with 0.1 mol/L of NaOH until pH 8.1 was achieved and expressed as gram of Citric acid per mL sample (Fadavi, Barzegar, Azizi, & Bayat, 2005; Mirsaeedghazi, Emam-Djomeh, Mousavi, Ahmadkhaniha, & Shafiee, 2010). The turbidity was measured using a portable turbidimeter (TU-2016, LUTRON-Taiwan) and expressed as NTU.

To measure the lycopene content, 2.5 g sample was added to 4 mL distilled water and stirred on the magnetic stirrer for 1 min. The solution was added to a solvent including hexane/acetone/ethanol (50–25–25%v/v) and the final solution was stirred for 10 min. The solution was followed by addition of 7.5 mL distilled water and stirring for 5 more minutes. The Erlenmeyer flask containing solution was kept immobile to reach the supernatant phase, then it was separated and diluted. Using UV–vis spectrophotometer (Photonix Ar 2015, Iran), the absorbance of the diluted supernatant phase was measured at 502 nm. Different concentrations of lycopene (10, 50, 100 and 150 mg/L) were used as standard (Alemi, 2009). Process concentration was performed in triplicates at each voltage and all physicochemical properties were measured at the beginning and end of each test, and the mean value of three repetitions was further recorded.

2.4. Engineering parameters

Electrical conductivity was calculated using the following equation:

$$\sigma = LI/AV \tag{2}$$

Where σ is the electrical conductivity (S/m), L is the gap between two electrodes (m), A is the cross-section area of the sample in the heating cell (m^2), I is the current (A), V is the voltage (V).

Due to evaporation of water, the contact area between tomato sample and electrodes was reduced and the tomato juice density raised continuously, thus an effective contact area and instantaneous density should be considered in above equation.

$$A = m_t/\rho_t L \tag{3}$$

$$\rho_t = \frac{m_t}{V_t} = \frac{m_t}{((V_{t-1}) - (V_{vaporized\ water}))}$$

$$\rho_t = \frac{m_t}{\left(\left(\frac{m_{t-1}}{\rho_{t-1}}\right) - (m_{t-1} - m_t)/\rho_{water}\right)} \tag{4}$$

$$\sigma = LI/AV = \rho_t L^2\, I/m_t V \tag{5}$$