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Pasteurization of fermented red pepper paste by ohmic heating

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ABSTRACT

Ohmic heating was applied to a Korean traditional fermented food containing red pepper paste, called *Gochujang* with low thermal conductivity (0.458 W/m · K), by varying frequencies (40–20,000 Hz) and applied voltages (20–60 V). Contrary to conduction heating, the entire sample was heated uniformly, and the specific heating rate was found to be highly dependent on the frequency, peaking at 5 kHz and 60 V. The results showed that complex differential equation and the Runge–Kutta fourth-order method are suitable for simulating the temperature profile during ohmic heating. The deactivation of vegetable cells of *Bacillus* strains on fermented red pepper paste by ohmic heating was indicated by a 99.7% reduction, compared with conduction heating for 8 min at 100 °C producing a 81.9% reduction. The organoleptic and physicochemical qualities of the samples pasteurized by ohmic heating were nearly the same as those of raw samples, and higher than those of conventionally heated samples.

Industrial relevance: The present study designed and implemented a novel sterilization process based on a static ohmic heating system with low-frequency AC at the laboratory scale for fermented red pepper paste with a low thermal conductivity (0.458 W/m·K).

The developed system was used to investigate the mechanisms and characteristics underlying the induction of ohmic heating and then, tested the pasteurization effect against microorganisms in fermented red pepper paste. Comparing with conventional heating processes, ohmic heating could provide rapid and uniform heating, thereby is more suitable for pasteurization and sterilization of viscous foods as fermented red pepper paste on industrial thermal processing.

1. Introduction

Heat transfer with driving forces based on a temperature gradient is generally used for the heating of foods. The quality deterioration of liquid foodstuffs with low viscosity after high-temperature exposure can be minimized by using high-temperature, short-time sterilization (HTST) or ultra-high temperature (UHT) sterilization. However, various problems are encountered when applying conduction heating to high-viscosity foods and foods comprising solid–liquid mixtures. *Gochujang* is a Korean traditional fermented food in the form of a red pepper paste that can have a high viscosity, making the use of a heat-exchange plate difficult. Moreover, its low heat-conduction coefficient means that heating needs to be applied for a long time in the sterilization process. These phenomena can result in overheating of the heating surface, producing a deterioration of food quality via the generation of off-flavors and decoloring reactions (Kim & Kwon, 2001; Lim, Kim, Kim, Mok, & Park, 2001; Yoo, 2001).

Given that the high viscosity of fermented red pepper paste restricts the usefulness of HTST and UHT sterilization, sterilization processes involving a tube-type heat exchanger and chemical treatments such as adding ethyl alcohol and sorbic acid have been commonly used. However, heating at 70–80 °C using a tube-type heat exchanger is not sufficiently effective at decreasing microbes, and most of consumers object to the addition of preservatives such as sorbic acid reactions (Kim & Kwon, 2001; Lim et al., 2001; Yoo, 2001).

Fermented red pepper paste is one of the most suitable materials for sterilization by ohmic heating. The electrical conductivity of food means that heat will be generated within its internal electrical resistance when alternating current (AC) is passed through it, thereby representing the conversion of electrical energy into heat energy; this heating method is called ohmic heating (Lee, Lee, Koh, & Lee, 2000; Parrot, 1992; Sastry & Sevugan, 1992). Microwave heating also involves the generation of heat by the conversion of electrical energy into heat inside food, via the vibration of water molecules on dipole rotation and ionic polarization of ions in a food. However, microwave heating tends to produce nonuniform increases in temperature due to (1) the limited penetration depth of the microwave irradiation and (2) the difficulty of ensuring irradiation by a uniform electromagnetic field at such high frequencies (especially in domestic microwave ovens). In contrast,

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ohmic heating has no limitations regarding the penetration depth as long as the inherent electrical resistance of the food is not too high. Moreover, liquids and solids on ohmic heating are heated simultaneously without requiring a stirring or mixing process of conventional heating (De Alwis & Fryer, 1990b).

Ohmic heating has been studied in various investigations of its application in commercial processes, such as for the sterilization of paste foodstuff with high viscosities and solid–liquid mixtures, the cooking and sterilization of seafoods such as surimi, and the thawing of frozen foods. Examples of developed equipment include the continuous ohmic heating system of a group in Cambridge and APV Baker in United Kingdom, the Joule heating system in Japan for the sterilization and molding of surimi, and the meat emulsion heating system and thawing machine for frozen fish blocks in Russia (De Alwis & Fryer, 1990a; Parrot, 1992; Wang & Sastry, 1993).

The present study designed and implemented a novel sterilization process based on a static ohmic heating system with low-frequency AC at the laboratory scale for fermented red pepper paste with a low thermal conductivity (0.458 W/m·K) (Chang & Chun, 1982). The developed system was used to investigate the mechanisms and characteristics underlying the induction of ohmic heating and then, tested the pasteurization effect against microorganisms in fermented red pepper paste.

2. Materials and methods

2.1. Sample preparation

Gochujang manufactured by a food processing company (Jinmi Food, Seoul, Korea) was used as the experimental sample and stored in a refrigerator (4 °C). The sample contained wheat flour, red pepper powder, milled glutinous rice, salt, corn syrup and water. Compositions of water, protein, fat, carbohydrate and ash of the sample were 43%, 8%, 4%, 27% and 18%, respectively, that can affect the heat generation on ohmic heating. The important properties of fermented red pepper paste were organoleptic quality based on taste, color and mouthfeel related to viscosity.

2.2. Experimental apparatus

A self-designed ohmic heating system was used in the experiments (Fig. 1). The power supply of the ohmic heating apparatus consisted of a function generator to generate sine and square waves from 40 Hz to 20 kHz, and an amplifier that can output 95-volt signals. An automatic multimeter, oscilloscope, and electrical conductance meter were used for the analysis and calculation of data. The heating cell (85 × 45 × 0.5 mm, W × L × T) was constructed from an upward-opening polypropylene box (90 × 90 × 50 mm, W × L × D), and aluminum was used as the electrode material. To ensure safety during the experiments, the heating cell was installed in a Pyrex box.

The electrical conductivity of liquid and paste foodstuffs was measured with an electrical conductor meter (CM-2A, Tokyo TOA Electronics, Tokyo, Japan). The current and voltage applied to the food during ohmic heating were measured using two digital multimeters (3500T, DM 303 TR, HC, Seoul, Korea), and the resistance of the food was calculated by applying Ohm's law to the measured current and voltage values. The waveforms produced by the function generator were observed on a two-channel 50-MHz oscilloscope (MO-1254 A, Meguro, Tokyo, Japan), including to measure their frequencies. A thermistor with a thermocouple (T type, Shinhan, Seoul, Korea) was used to measure center temperature on heated sample. The maximum temperature variability within the sample was 2 °C.

2.3. Experimental procedure

The sample was placed inside the heating cell of the ohmic heating of batch type apparatus, and then its ohmic heating characteristics as electric conductivity and heating rate were examined at various frequencies (40–20,000 Hz) and applied voltages (20–60 V). The effects of the internal ohmic heat generation of the frequency and voltage on the pasteurization of fermented red pepper paste were investigated. Also, polynomial approximation, complex differential equation and the Runge–Kutta fourth-order method were used to simulate the temperature profile of fermented red pepper paste on various frequencies and voltages during ohmic heating.

An experiment was also performed to implement conventional conduction heating, involving measuring the temperatures when the sample packaged in an aluminum box of the same size as the ohmic heating cell was immersed in water at 70–100 °C. Sensory evaluation and analysis for physiochemical properties were conducted for comparing between products applying ohmic heating and conventional conduction heating.

2.4. Measurements of pH and acidity

In order to measure pH of homogeneous fermented red pepper paste, 3 g of the each sample was mixed with 30 mL of distilled water and the diluted solution was centrifuged at 1400 ×g with a centrifuge (1248R, GYROZEN, Seoul, Korea). The pH of the supernatant was measured by a pH meter (420A, Orino, Tokyo, Japan) at room temperature.

The acidity of the sample was analyzed by a quantitative method with lactic acid. A 10-mL aliquot of supernatant of the sample obtained by centrifugation was diluted with 10 mL of distilled water, and then titration of sample was performed by end-point checking as the retention of light redness during 30 s with the addition of 0.5 mL of 1% phenolphthalein and 0.1 N NaOH:

$$\text{Lactic acid } (\%) = [\textit{titration volume of } 0.1\ \textit{N NaOH}\ (\%) \times \text{Factor of NaoH} \times 0.009]/[\text{weight of sample } (g)]. \quad (1)$$

2.5. Color measurement

The color values of samples were measured by a spectrophotometer (UV-120-02, Shimadzu, Tokyo, Japan). A 0.5-g sample and 20 mL of acetone were mixed for 10 min, and then the OD value was measured at 460 nm. The color value of *Gochujang* was calculated as

$$\text{Color value} = [\text{OD value}/(\text{weight of sample(mg)})] \times 1000 \times \text{dilution multiple}. \quad (2)$$

2.6. Sensory evaluation

The organoleptic characteristics of the samples were determined by a trained panel consisting of 10 students in the Department of Food Engineering, Yonsei University. After completing three training sessions related to descriptive profiling, the multiple comparison test was conducted for evaluating sensory attributes such as taste, color, flavor, texture, and overall acceptability of the fermented red pepper paste. All samples were the same weight and each was served on a randomly coded plate and water was provided to the panelists to cleanse the palate after tasting each sample. The panelists rated the preference of sensory attributes from 1 (extremely bad) to 5 (extremely good) for each sample on a 5-point hedonic scale.

2.7. Microbiological analysis

In order to identify the viability of microorganisms in fermented red pepper paste, 10 g of each sample was placed in 100 mL of sterile distilled water and pummeled for 3 min at 9 h/s with a Stomacher (HBM-400A, Tianjin Hengao, Tianjin, China). The mixture was serial diluted and spread on plate count agar (PCA, Difco Lab., Detroit, MI, USA) and incubated for 24 h at 37 °C. After the incubation, the number