Journal of Food Engineering 113 (2012) 275–280

Contents lists available at SciVerse ScienceDirect

Journal of Food Engineering

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

Accelerated texture softening of some root vegetables by Ohmic heating

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ARTICLE INFO

Article history:
Received 24 August 2011
Received in revised form 27 April 2012
Accepted 27 May 2012
Available online 5 June 2012

Keywords:
Texture
Ohmic heating
Microwave
Conventional heating

ABSTRACT

Effects of different thermal processing methods (Ohmic heating, high and low power, microwave and conventional heating) on textural properties of cylindrical pieces of root vegetables of carrot, red beet and golden carrot were investigated and compared with conventional and microwave processes. The samples were subjected to different processing methods and textural parameters of the processed samples were analyzed using texture profile analysis (TPA) at different processing times. Texture parameters-processing time data were fitted into a previously suggested equation and texture softening rate (K) and residual constant (A) values were calculated. From the K and A values it can be concluded that not only Ohmic heating resulted in greater softening rates but also the final hardness of the samples treated by Ohmic heating was significantly lower than those of other samples treated by either conventional or microwave methods. Negative correlations were found between texture hardness and weight loss of all samples undergone different processing methods.

1. Introduction

Ohmic heating (also referred to as Joule heating, electro heating, and electro conductive heating) is defined as a process wherein an alternating electrical current is passed through materials (Vicente et al., 2006; Goullieux and Pain, 2005) and can be used to generate heat deep inside the product (Imai et al., 1995). The heating occurs in the form of internal energy transformation (from electric to thermal which is due to Joule effect) within the material (Sastry and Barach 2000). Ohmic processing heats materials at extremely rapid rates (Sastry, 2005). Electrical conductivity is the main parameter determining the heating rate of an Ohmic heating treatment. The electric conductivity of food products usually increases with water content and temperature. This variation is due to increased ionic mobility at elevated temperatures and is a function of the concentration of individual ions represented by the diffusion coefficient. For cellular foodstuffs such as vegetables the cell membrane is an electrical insulator and current flow is confined principally to the intercellular fluid. High extracellular and intracellular ion concentrations lend a high electrical conductivity to the solution progressing through the cell wall into the microtubules. Distilled water is an electrical insulator so in many studies on Ohmic technology, salted water is used as the liquid phase for Ohmic treatments (Goullieux and Pain, 2005).

In the nineteenth century, several patents were filed for the use of direct resistance heating for the sterilization of static liquid foods. In 1993, with the Food and Drug Administration (FDA) approval, process of stable low acid foods at ambient temperature became legal. Since then, Ohmic heating has been used commercially in Japan, the USA and Europe.

Ohmic heating technology presents a large number of current and potential future applications, including its uses in blanching, evaporation, dehydration, fermentation, extraction (USA-FDA, 2000), sterilization, pasteurization and heating of foods to serving temperature in the military field or long-duration space missions (Sastry et al., 2009).

Microwaves directly interact with food components and heat is generated volumetrically deep inside.

The mechanisms of microwave heating of foods can be categorized into two groups: dipolar rotation and ions mobility. Some dielectric materials such as water contain permanent dipoles that tend to reorient under the influence of an alternating field thus causing orientation polarization. Heat is generated as a result of friction between rotating molecules under the alternating field (Sumnu & Sahin, 2005).

Food texture and its changes during processing are of key importance for process design including washing, peeling, handling and heat treatment. Quality and acceptance of food products by the consumers are also affected by their textural and mechanical properties. Texture of many fruits and vegetables is classified as critical to the consumers and if damaged could have profound effects on their acceptance quality. Texture of some foods including processed vegetables determines the heat treatment processing time. Therefore optimization of textural changes of vegetable tissues could have some advantages for redesigning of processing lines in order to shorten the overall process time (limiting the heat treatment), energy saving and less heat damage to heat sensitive

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http://dx.doi.org/10.1016/j.jfoodeng.2012.05.039

components including vitamins and other bioactive compounds (Mayor et al., 2007).

Ohmic heating as a rapid heating method with a more uniform heat distribution than other electro heating techniques (Gavahian et al., 2011) suggests promising potentials of this technique towards controlled modification of food texture. Therefore one aspect of Ohmic heating applications could be regarded as texture and rheological properties of foods materials. In a study on guava juice extraction, it was shown that Ohmic treatment of fresh guava fruits with alternating current of 100 V can increase the juice extraction significantly, however, some negative effect on flavor was reported. This was related to textural destruction caused by Ohmic heating (Srikalong, et al., 2011). Aseptic processing of apricots in syrup by means of a continuous pilot scale Ohmic unit was performed and acceptable sensory properties were reported during storage (Pataro et al., 2011).

The objectives of this study are to investigate the kinetics of textural softening of root vegetables of carrot, red beet and golden carrot subjected to Ohmic heating and compare it with conventional and microwave heating.

2. Materials and methods

2.1. Materials

Carrots, red beets and golden carrots of good and uniform quality were purchased from a local supermarket and kept in a cold room (4 °C) in sealed plastic bags to avoid any unwanted moisture loss before further experiments. All materials used were of analytical grade unless otherwise mentioned.

2.2. Sample preparation

The top and bottom ends of each sample were cut off. Cylindrical shape samples with diameter and height of 25 mm were then prepared using a cylindrical sample cutter (Instron, USA) and a sharp knife. After weighing the individual specimens, they were immediately dipped into a 1.5% NaCl aqueous solution at 95 °C. At the start of each process, boiling NaCl water aqueous was used for all heating methods to delete the effect of come up time (the time required to heat the water to boiling temperature) and avoid unwanted system complexity. Mixtures of each root vegetable and boiling water were then quickly transferred to different processing equipments (conventional heater, microwave and Ohmic heater) and the equipment switched on. At known time intervals, the samples were taken and cooled (processed samples were immersed in a 500 cc beaker of tap water (20 °C) for 3 min). The surface of each sample was then dried using blotting paper. Textural analysis and water loss test were then performed.

2.3. Thermal processing methods

Four cooking methods, (1) conventional heater, (2) microwave, (3) low Ohmic heating with voltage of 220 V and (4) high Ohmic heating with voltage of 380 V, were used in this study.

(1) *Ohmic cooking*: Ohmic heating was performed using a cylindrical Ohmic device made of Pyrex with the length and diameter of 51 and 9 cm, respectively equipped with stainless steel 304 electrodes, designed and developed in the Department of Food Science and Technology of Shiraz University (Farahnaky et al., 2010). Processing parameters (e.g., processing time, temperature and power consumption), were precisely monitored using a software developed and coupled with a Wattmeter to record the input power of Ohmic apparatus to double check the data given by the software. To investigate the effect of voltage on textural properties, Ohmic cooking was performed at 380 and 220 V, 50 Hz. As for Ohmic cooking at 380 V, the samples were treated for 1.5, 3, 5 and 8 min. For low Ohmic at 220 V, red beet and golden carrot were treated for 3, 5, 8, 11 and 13 min, and carrot was treated for 2, 5, 6, 8, 11, 14, 17 and 19 min. Time interval differences between the samples were due to textural differences between the samples. The device operated at 220 and 380 V. The computer monitored the temperature, current and voltage applied.

(2) *Microwave cooking*: A 2000 cc glass beaker including the mixture of sample (4 pieces each time) and NaCl solution was placed in a microwave oven (LG MW oven (MC-789Y) operating at 2450 MHz and power of 900 W. The samples were taken at 5, 10, 15, 20, 25 and 30 min of cooking times for further experiments.

(3) *Conventional cooking*: Conventional heating process was performed using a laboratory heater (MAG-K; Gerhardt Ltd., Germany; and 500 W) set at its maximum power setting, instead of Ohmic distillator. The container used for heating the samples was the same as for microwave heating. The samples were taken at processing times of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55 and 60 min, for further experiments.

For all processing methods, solution volume was constant and 1.5 L of NaCl solution was used each time.

2.4. Textural measurement

The texture of root vegetable samples was studied using a texture analyzer (Texture Analyzer, TA Plus, Stable Microsystems, Surrey, England) with a load cell of 30 kg, by performing texture profile analysis (TPA). TPA involves a double compression force test using a cylindrical probe having dimensions greater than the sample dimensions. Samples were compressed to 15% of their original height by two consecutive compressions using a cylindrical probe of 100 mm diameter. The crosshead speed was maintained at 1 mm/s. The waiting time between the two-cycles of the TPA test was 10 s. Texture profile parameters (hardness, gradient and compression energy) were calculated from the compression force versus distance (or time) curves using the Texture Exponent Lite developed and supplied by the manufacturer. Hardness as maximum force of the first compression peak, gradient as slope of the first compression force curve versus time and compression energy, area of force-distance curve until maximum force were calculated. All textural measurements were performed at room temperature (22 ± 2 °C) on four replicates for each sample.

2.5. Change in textural properties with cooking time

The kinetics of texture changes (softening) and thermal sensitivity of fruits and vegetables are important factors in formulation and thermal processing of new products aiming at optimizing quality attributes of final products (Haralampu et al., 1985). An approach frequently applied in food softening studies has been to express the change of a texture parameter X with the time t by a first order relation with apparent rate constant k (Eq. (2)) (Verlinden, 1996).

$$dX/dt = -kX \text{ with } X(t = 0) = X - 0; \text{ or } X = X_0 exp(-kt) \quad (1)$$

The texture parameter X represents the output of a texture measurement method, such as penetrometer force, rupture stress in a tensile test, compression force in this current study and so on. Other researchers (Tijskens and Schijvens, 1987) have added another term called “constant A” (residual texture) to the model,