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Experimental comparison of microwave and radio frequency tempering of frozen block of shrimp

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ABSTRACT

In this study, microwave and radio frequency tempering of frozen shrimp were compared experimentally in terms of tempering rate and uniformity. To do this, a block of frozen shrimp (1.75 kg) was tempered from an initial temperature of − 22 °C to between − 5 and − 3 °C both in a microwave system (915 MHz) and a radio frequency oven (27.12 MHz). Temperatures at four different internal locations were recorded during tempering experiments by using a signal conditioner and fiber optic probes. Surface temperature was also measured using an infrared camera immediately after tempering. Time needed for temperature increase from the initial to between − 5 and − 3 °C at all four locations where the fiber optics were inserted was about 10 and 4 min for power settings of 500 W and 1 kW respectively when microwave tempering was performed. In case of radio frequency tempering, it took 11 and 7 min to reach between − 5 and − 3 °C at all four locations for electrode gaps of 160 and 150 mm, respectively. Among all treatments, microwave tempering at 500 W yielded the most uniform internal temperature distribution. However, local surface overheating was observed during microwave tempering at both power settings. Radio frequency tempering, in contrast, was found to result in a uniform overall temperature distribution with no local overheating at the surface.

1. Introduction

Frozen foods are usually thawed or tempered before further processing in food industry. In thawing, thermal center of the frozen product reaches 0 °C. However, lower temperatures (usually − 5 to − 2 °C) are targeted in tempering. At this temperature range the frozen product is not completely thawed but softened, and hence can readily be further processed (Yarmand and Homayouni, 2011).

Thawing of frozen blocks of meat and seafood by microwave and radio frequency has been commercially applied due to several advantages of electromagnetic thawing over conventional thawing methods. These advantages include reduced thawing time and less damage to product quality owing to the volumetric heating characteristic of electromagnetic energy. In addition, drip loss is minimized and microbial safety is not compromised when electromagnetic thawing methods are used (Li and Sun, 2002).

Comparison of electromagnetic and conventional thawing in terms of tempering rate and uniformity has been conducted in several studies (Farag et al., 2008a and 2011; Zhao et al., 2000). Farag et al. (2008a and 2011) showed that radio frequency application provides significant reduction in tempering time (from hours and even days to minutes) when compared to conventional air tempering. An 85-fold reduction in tempering time along with a comparable uniformity of temperature distribution was reported by Farag et al. (2011) when RF tempering was employed. Farag et al. (2008a) compared the temperature distributions in 4-kg beef blends tempered by radio frequency (27.12 MHz) and conventional air tempering. In RF tempering experiments, they targeted temperatures between − 5 and − 2 °C and reported that 11 min at 500 W was the optimum RF power-time combination yielding an average temperature of − 3.6 ± 1.1 °C. They found in another study (Farag et al., 2011) however that when higher temperatures (− 1 to 5 °C) were targeted (thawing), a considerably longer time (35 min) was needed at 400 W as completion of the phase change zone required a large amount of energy (Fu, 2004). Wang and Goldblith (1976) also showed that twice as much energy was required to temper frozen beef from − 17.7 °C to − 2.2 °C than to temper it to − 4.4 °C. Furthermore, the optimum treatment in terms of temperature distribution was obtained by employing a power program (20 min on + 10 min off + 15 min on). Again, Zhao et al. (2000) reported 12.5 min for RF thawing, 3 h for water and 16 h for air thawing for 3.18 kg block of kippers (38.1 × 25.4 × 3.8 cm).

Comparative study of radio frequency and microwave heating was performed only by a limited number of researchers (Dubey et al., 2016; Choi et al., 2017). Dubey et al. (2016) used a 19 MHz RF system and a

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2.45 GHz microwave oven with an equivalent heating power (3.4 kW) and measured temperature at different depths of wood. While similar heating rates were observed for RF and microwave treating of wood with cross-sectional dimensions of 10 × 10 to 15 × 15 cm, > 40% faster and more uniform heating was achieved with the RF system when the dimension was above 15 × 15 cm. Choi et al. (2017) investigated the effect of various tempering methods (forced air, water immersion, radio frequency, and microwave) on tempering rate of frozen pork loin (100 × 100 × 70 mm). A 19-fold reduction in tempering time (time to bring pork loin from − 20 to − 2 °C) was observed with the radio frequency system when compared to forced air treatment. Microwave tempering was, however, found to be the fastest method of all. It should be noted here that a domestic microwave oven operating at 2.45 GHz was used in their study.

In the present study, tempering performances of a microwave and a radio frequency system operating at frequencies commonly used in industrial scale thawing equipment were experimentally compared in terms of tempering rate and uniformity. Tempering at two different power settings in both methods were studied by using a frozen block of shrimp as the model.

2. Materials and methods

Tiger shrimps (75–80 count per kg, moisture content 81% by weight), peeled/beheaded and weighing 1.75 kg, were frozen as a block (23.0 × 16.8 × 5.0 cm) in a cardboard box using a top-loading freezer (Arçelik, Model 2536 A + + D, Turkey) with a capacity of 232 L.

2.1. Microwave tempering

Microwave tempering system (Sonar, Izmir, Turkiye) specially designed in our laboratory consisted of a 5 kW magnetron operating at 915 MHz, a rectangular waveguide and a cylindrical cavity (Fig. 1). System power was adjustable in 500 W intervals. The cavity (25.4 cm height and 54.0 cm diameter) had a removable top cover with a 25-mm hole in the center. This hole was used to run the fiber optic temperature probes into the cavity. The system was equipped with a turntable to improve heating uniformity. In fact, rotation was required during microwave treatment in order to avoid runaway heating. The turntable completed one revolution in 88 s. The frozen block in cardboard box with its top open was placed on the turntable in the center of the cavity. The orientation of the block with respect to the waveguide was the same in all experiments when the system was turned on. Microwave tempering experiments at two different power settings (500 W and 1 kW) were conducted in duplicate.

2.2. Radio frequency tempering

Radio frequency tempering was conducted by using a laboratory scale free-running oscillator radio frequency (RF) system with a parallel plate electrode design operating at a frequency of 27.12 MHz and a maximum power of 2 kW (Sonar, Izmir, Turkiye) (Fig. 2). Electrode width and length were 43 cm and 100 cm, respectively. The top electrode was movable so that the gap between the electrodes could be adjusted. The largest gap setting that can be adjusted in the RF system was 160 mm, while 150 mm was the lowest gap setting that can be used in order to avoid bending of the fiber optic probes. Radio frequency tempering experiments were conducted in duplicate at electrode gap settings of 150 and 160 mm. The frozen block of shrimp in cardboard box was placed on a turntable between and in the horizontal center of the electrodes. Radio frequency tempering was employed with and without rotation (horizontal) to see the possible effect of moving the sample on heating uniformity. The distance between the upper surface of the block and the top electrode was 46 and 56 mm for the gap settings of 150 and 160 mm, respectively.

2.3. Temperature measurement

Temperatures at four different internal locations were recorded with 1 sec interval by using a 4-channel signal conditioner and fiber optic probes (UMI-4, FISO, Canada). To do this, four holes with a depth of 25 mm were drilled at pre-defined positions as depicted in Fig. 3. In order to get a good representation of the temperature distribution within the block, probes were inserted into the block to measure temperature at the geometrical center (center), midway between the geometrical center and the edge (mid), close to the edge (edge) and close to the corner (corner). Tempering was terminated when at least − 5 °C was attained at all probe locations.

Surface temperature was measured immediately after tempering using a thermal camera (Model PI200, Optris, Germany). The frozen block was positioned so that the camera was able to see the whole upper surface. The emissivity setting was adjusted to be 0.95, since water and most organic materials such as foods have an emissivity close to 0.95 (Powitz, 2006). A rectangular area that included only the shrimp block was defined on the acquired thermograms. Then; minimum, maximum, and average temperatures within this area were obtained. Standard deviation of the temperatures observed at the upper surface was also calculated to provide a measure of surface temperature distribution.

2.4. Power measurement

During RF tempering, power absorbed by the frozen block of shrimp was estimated using the electrical current (I) values displayed on the PLC screen of the radio frequency oven from the relationship of $P = VI$. To do this, the current readout during system running without load at the adjusted electrode gap was subtracted from the current value displayed during tempering (with load), and the result was multiplied by 3000 V (voltage applied to top electrode as provided by the manufacturer).

An approach similar to the IMPI 2-liter test as detailed by Buffler (1993) was also used to determine the power converted to heat (heat

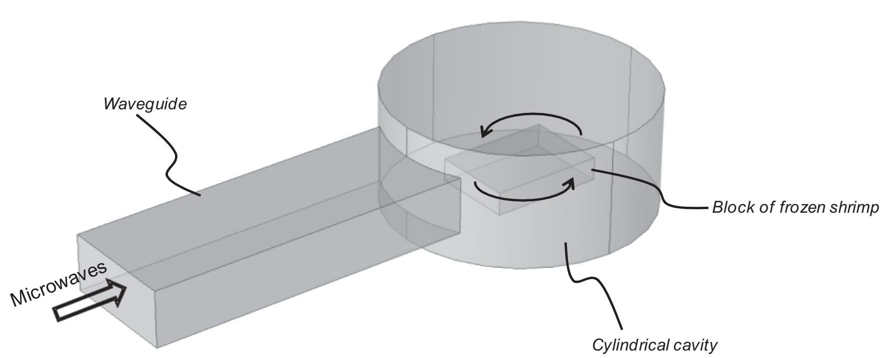

Fig. 1. Schematic of the microwave tempering experimental setup.