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Physical properties of egg whites and whole eggs relevant to microwave pasteurization

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ABSTRACT

Microwave pasteurization is a novel thermal processing technology in which non-uniform heating may be a major challenge. In this study, the suitability of using egg whites (EWs) and whole eggs (WEs) as model foods to evaluate the heating uniformity and to determine the cold and hot spots during microwave pasteurization was investigated. The samples were prepared from mixtures of water with commercial EW or WE powders at different solid concentrations (20%, 25%, 27.5%, and 30%) and salt contents (0, 50, 100, and 200 mM). Critical physical properties for desirable model food systems include appropriate dielectric properties, gelation temperatures, gel strengths, and water holding capacities (WHCs). The gelation temperature of liquid EW and WE were 70 and 80 °C; both fell in the pasteurization temperature range. At 915 MHz, the dielectric constants of liquid EW and WE samples and their heat induced gels decreased with solid concentration while the loss factor was not affected. Loss factors of liquid EW and WE samples increased linearly with salt addition, which could be explained by the linear increase of electrical conductivities by adding salt. The strength and WHC of heat induced EW and WE gels increased linearly with solid concentration, while salt addition had no significant effect. The results demonstrated the suitability of using EW and WE as model foods to determine the heating uniformity during microwave pasteurization process.

1. Introduction

Microwave-assisted thermal processing is a novel thermal processing technology that provides rapid volumetric heating (Ohlsson, 1991). It overcomes the slow heating in conventional thermal processes, so that better product quality could be retained. In October 2009, a process for mashed potatoes (homogeneous food) based on the 915 MHz microwave assisted thermal sterilization (MATS) system developed at Washington State University (WSU) was accepted by the US. Food and Drug Administration (FDA), followed by a second FDA acceptance for microwave assisted sterilization of salmon fillets in Alfredo sauce (non-homogeneous food) in December 2010. Similar to microwave sterilization, microwave assisted pasteurization (MAP) also utilizes the microwave energy to quickly raise product temperatures to desired levels to inactivate viable pathogens in foods. A 915 MHz MAP system is currently under development at WSU for cold-storage prepacked foods.

A major challenge for developing microwave-assisted thermal processes is possible non-uniform heating patterns caused by the factors influencing the electromagnetic field, such as food properties, package geometry, and location of the product inside the microwave applicators (Keefer and Ball, 1992; Stanford, 1990). In the development of MATS processes, whey protein gels (WPGs) with chemical marker precursors were found useful to map the heating patterns using a computer vision method (Pandit et al., 2007; Wang et al., 2009b). However, WPGs are not suitable for microwave pasteurization due to their high gelling temperature at around 90 °C. It is thus essential to develop new model food systems for MAP processes.

Natural egg components including egg white and whole egg can form heat-induced gels. Their gelation temperatures vary from 42 to 78 °C at different pH, salt, and sugar levels (Raikos et al., 2007), which are all in the pasteurization temperature range. Powdered eggs (produced by drying, mostly spray-drying, from the liquid eggs) in homogeneous form have an extended shelf life, and can be easily and consistently reconstituted into the liquid form with different solid concentrations. Thus, EW and WE can be conveniently used to form model foods.

In microwave processing, heat is generated volumetrically inside the material by converting electromagnetic energy into thermal energy. The dielectric properties of the model foods dictate how the microwave energy is absorbed, transmitted, reflected, or concentrated. They are of great importance for understanding the behavior of model foods during microwave heating (Datta and

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Ananthesweran, 2001). The dielectric properties of foods include the dielectric constant ε_r' and the dielectric loss factor ε_r'', which are the real and imaginary parts of the relative complex permittivity ε_r:

$$\varepsilon_r = \varepsilon_r' - j\varepsilon_r'' \tag{1}$$

where $j = \sqrt{-1}$, ε_r' indicates the ability of a material to store electric energy, and ε_r'' reflects the ability of the material to dissipate electromagnetic energy into heat (Nelson and Datta, 2001). The rate of energy generation per unit volume (Q) in the material can be calculated from (Dibben, 2001):

$$Q = 2\pi f\ \varepsilon_0\varepsilon_r''E^2 \tag{2}$$

where E is the strength of electric field, ε_0 (8.8542×10^{-12} F/m) is the permittivity of free space, and f is the frequency.

The dielectric properties of natural hen egg components have been investigated by many researchers for storage studies, protein denaturation determinations, or effect of thermal treatment investigation (Bircan and Barringer, 1998; Ragni et al., 2007; Dev et al., 2008; Wang et al., 2009a). However, there was no study on the effects of solid concentration or salt content on the dielectric properties of the egg proteins. One of our objectives was to explore the possibility of generating a wide range of dielectric property values of egg proteins by changing solid and salt contents to match potential foods to be processed by MAP.

The heat induced gelation of egg proteins is a transition from a fluid-like to a solid-like viscoelastic structure (Montejano et al., 1984). Physical properties such as gelation temperature, gel strength, and water holding capacity (WHC) are also important for evaluating the suitability of EW and WE as model foods. The gelation temperature (the onset temperature at which the gelation occurs) determines whether the liquid EW and WE can solidify at the pasteurization temperatures to form solid model foods. It can be affected by the protein concentration, ion concentration, pH, and possible interaction between protein and other components (Yasuda et al., 1986). Gel strength indicates if the model food has a proper texture to hold its shape, and if it is proper for cutting and post-process evaluation. WHC is the ability of a gel to hold water in its network structure, indicating the ability of the model food to retain its geometry and size during and after the process.

The objectives of this study were to investigate the effects of solid concentration and salt content on physical properties (including dielectric properties, electrical conductivity, gelation temperature, gel strength, and WHC) of liquid egg white and whole egg samples and their heat induced gels, in order to evaluate their suitability as model foods for microwave pasteurization. The data can also be used as reference for processing of egg products using microwave pasteurization.

2. Materials and methods

2.1. Sample preparation

Commercial "Just Whites" all natural egg white powder (0% total fat, 2% sodium; Deb-El Foods Corporation, Elizabeth, NJ, USA) and "Honeyville Farms" whole egg powder (8% total fat, 3% sodium; Honeyville Food Products, Brigham City, UT, USA) were used to produce homogeneous liquid EW and WE samples. To study the effect of solid concentration on the physical properties, EW and WE were prepared with solid concentrations of 20%, 25%, 27.5%, and 30% (wb). Salted EW and WE samples were prepared by adding salt of 0, 50, 100, and 200 mM into liquid EW and WE samples with solid concentration of 25%. In the preparation of the liquid samples, a pre-determined amount of EW or WE powder was reconstituted using 35 °C double deionized (DDI) water and mixed for 3 min using a magnetic stir. Pre-determined amounts of table salt were added to the mixtures and further stirred for 15 min. The mixtures were held in a water bath at 35 °C for 20 min, and the n kept at room temperature overnight before use. Part of the liquid mixtures was then used for the determination of dielectric properties, electrical conductivities, and gelation temperature. Separate samples were filled into glass bottles (diameter = 40 mm; height = 30 mm), heated in a water bath at 85 °C for 30 min, and cooled in tap water for 20 min to form gels. The gels were used for the determination of gel strength and WHC. For each physical property measurement, duplicate sets of samples were prepared.

2.2. Dielectric properties

An HP 8752 C network analyzer (frequency range: 300–3000 MHz) and 85070B open-end coaxial dielectric probe (Agilent Technologies, Santa Clara, CA, USA) were used for the dielectric properties measurement (Fig. 1). After the instrument was warmed up and calibrated, liquid EW and WE samples were filled into the custom-built stainless steel test cell (20 mm inner diameter, 94 mm height). The test cell was connected to a circulating oil bath (Ethylene: water = 9:1) with programmable circulator (1157, VWR Science Products, Radnor, PA, USA) for temperature control. The liquid in the oil bath was pumped into the space between the two walls of the test cell to heat the sample from 22 to 100 °C. A thermocouple was inserted into the sample from the lower end of the test cell to monitor the temperature. The measurement was triggered at every 10 °C temperature increment. A stainless steel spring and piston inside the test cell compresses the sample tightly to the dielectric probe after heat-induced gelation in order to ensure the contact between the probe and the sample. 201 points were recorded through the whole frequency range of 300-3000 MHz. After each measurement, the test cell was dipped into ice to cool down. A more detailed description of the system and measurement procedure was described by Guan et al. (2004). All measurements were conducted in duplicate.

2.3. Penetration depth

Penetration depth (D_p) of microwave power in a dielectric material is the depth where the incident power decreases to $1/e$ ($e = 2.718$) of its original value at the material surface. D_p can be calculated from:

$$D_p = \frac{c}{2\pi f\sqrt{2\varepsilon'\left[\sqrt{\left(\frac{\varepsilon''}{\varepsilon'}\right)^2 + 1} - 1\right]}}\ (\mathrm{m}) \tag{3}$$

where c is the speed of light in free space as 3×10^8 m/s, f is the frequency (Hz) (Buffler, 1993), which is 915 MHz in this study.

2.4. Electrical conductivity

A CON-500 Electrical Conductivity meter (Cole-Parmer Instrument Co., Vernon Hills, IL, USA) was used for the electrical conductivity measurements of liquid EW and WE samples (25% solid concentration, wb) at room temperature. The probe was kept immersed in the solutions and the readings were recorded after the temperatures reached equilibrium. All measurements were made in triplicate.

2.5. Gelation temperature

The gelation temperature can be studied by different methods, including Differential Scanning Calorimetry (DSC) (Ahmed et al., 2007) and rheological methods such as small amplitude oscillatory shear (SAOS) (Ould Eleya and Gunasekaran, 2002; Croguennec