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Rapid (microwave) heating rate effects on texture, fat/water holding, and microstructure of cooked comminuted meat batters

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ABSTRACT

Comminuted and gelled, fat-containing meat products such as frankfurters and luncheon meats are commercially processed by heating relatively slowly (for up to 2 h or more) to an endpoint of about 70 °C prior to cooling. This study compared such a slow, ramp heating regime (0.5 °C/min), terminated at 70 °C, to rapid, square-wave cooking (one step: rapid 100 °C/min heating to 70 °C endpoint, plus isothermal holding prior to cooling, or two-step: rapid heating to 50 °C, holding, then rapid heating to 70 °C plus holding prior to cooling) on meat batter gel properties (fracture and small strain rheology, microstructure, cook loss, and expressible water). The results indicated that a rapid cooking process, with its inherent advantages of reduced process time, lower equipment footprint, and more efficient use of energy, can produce a product nearly equivalent in textural properties and cook yield to one processed by traditional smokehouse cooking when the cook value of the processes is similar and an intermediate (near 50 °C) holding step is included (two-step rapid heating). One-step rapid heating negatively affected gel structural homogeneity and water/fat holding properties of fat-containing gels.

1. Introduction

Comminuted meat gel products from mammalian and avian meats, which would include such products as hot dogs and bologna, are prepared by first chopping meat with the addition of salt, ice water, fatty tissues and seasonings to a fine homogenate, or batter. A thermo-irreversible gel matrix forms upon staged or slow ramp heating, typically requiring 2 h or longer to reach a desired endpoint temperature of 70–72 °C (Zayas, 1997), whereupon the product is then rapidly cooled. Such a slow heating rate is necessitated partly because conductive heat transfer in the industrial ovens ('smokehouses') used for cooking would overcook the outer portion of the product if the heating rate was too rapid; maintaining a low ΔT between product surface and center helps minimize this. The time-consuming process and large footprint of such ovens, plus the wasted energy and time involved in their equilibration prior to commencing cooking, could be ameliorated by adopting rapid heating methods such as radio-frequency (RF), microwave, or ohmic (rapid) heating.

But a slow heating rate is thought to maximize yield and desirable texture in such products (Komarik, Tressler, & Long, 1974). Many workers have reported that a faster heating rate adversely affects the heat-induced gelation of both globular and myofibrillar protein sols or pastes relative to producing a homogeneous gel structure exhibiting desirable texture and water/fat holding properties (Barbut & Mittal, 1990; Camou, Sebranek, & Olson, 1989; Gossett, Rizvi, & Baker, 1984; Yongsawatdigul & Park, 1996; Yoon & Park, 2001). Foegeding, Allen, and Dayton (1986) compared similar treatments for purified myosin sols and found that rapid heating always resulted in lower gel strength (rigidity) than slow heating. The explanation offered is that during rapid heating there is insufficient time for proteins to denature and properly align prior to aggregating to form the gel structure, resulting in gels that are more coarse and weak (Hermansson, 1978; Schmidt, Mawson, & Siegel, 1981). This derives from the two-step theory of protein gelation advanced by Ferry (1948) which, simply stated, asserted that a protein dispersion upon heating first denatures to expose active sites that can then align and aggregate to form a gel (Ferry, 1948).

However, most of the foregoing studies compared effects of process treatments that, while varying in heating rate, also greatly differed in cook value (CV), the integrated heating time with respect to physical and chemical changes of product quality (Houben, Schoenmakers, Van Putten, Van Roon, & Krol, 1991). This occurred because heating at the varying rates being compared was always terminated by rapid cooling upon reaching the same endpoint temperature. Riemann, Lanier, and Swartzel (2004) compared rapid, square-wave heating to slower ramp heating for low fat Alaskan pollock (surimi) and turkey breast meat pastes. They concluded that rapid heating, plus isothermal holding at the endpoint temperature, yielded similar cooked gel properties (fracture stress and strain, cook loss) as those obtained by slow cooking just to the same endpoint temperature when the processes were approximately equal in CV.

Fat-containing batters could present a greater challenge for the application of rapid heating techniques. Rapid heating might not allow

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sufficient time for meat protein gelation to properly occur prior to fat fluidization, or could lead to formation of a less homogenous gel structure which, even if displaying similar rheological and water holding properties as reported by Riemann et al. (2004), could nonetheless entrap the fluid fat less well. While there have been reports of good fat stability in rapidly heated (by RF or ohmic) high-fat meat batters (Shirsat, Brunton, Lyng, & McKenna, 2004; Shirsat, Brunton, Lyng, McKenna, & Scannell, 2004), the formulations used in these studies all included other additives that might enhance fat binding: one group added 4% beef plasma, and the other two a large percentage of soy and grain product. Even with such additives, however, Shirsat, Brunton, Lyng, & McKenna (2004) reported decreased springiness in ohmically-cooked meat emulsion gels, which could relate to structural differences in the protein matrix formed.

Lanier and Labudde (1995) reported that, when attempting to cook using a water bath, only by heating a comminuted meat product in two stages could they produce a product with similar rheological and fat/water holding properties as when the product was slowly ramp heated as in a commercial smokehouse. They first heated frankfurter pastes, sealed in cellulose casings, at 50 °C for 30 min, then transferred the casings to a 70 °C water bath to finish cooking the product for 45 min prior to subsequent cooling. No non-meat additives were used in their formulations for the enhancement of fat binding; rendered fat (lard) was the main fat ingredient.

Swift, Townsend, and Witnauer (1968) concluded that fat physical properties can greatly affect fat stability of comminuted meat products. The fats used in comminuted meat products are from animal adipose tissue primarily composed of neutral lipids (triglyceride) wherein the ratio and composition of saturated-to-unsaturated fatty acids in triacylglycerols impart the characteristics specific to that fat in terms of melting temperature and thus fluidity or hardness at a given temperature. Acton, Ziegler, and Burge (1983) stated that, in order to produce stable meat products, for most formulations made with pork and beef fat the final chopping temperature should not exceed 16 to 18 °C whereas a maximum of 10 to 12 °C should be used for meat products made with poultry fat.

However, some researchers have reported that substituting animal fat with different types of liquid oils, such as peanut, olive, sunflower, and soy oils, showed little effect on emulsion stability (i.e. fat release during cooking) or on the smokehouse yield of frankfurters (Ambrosiadis, Vareltzis, & Georgakis, 1996; Hammer, 1992; Marquez, Ahmed, West, & Johnson, 1989; Park, Keeton, & Rhee, 1989). Two studies (Bloukas & Paneras, 1993; Paneras & Bloukas, 1994) did report some adverse effects of using oils vs fats, but also reported that reduced-fat frankfurters (10%) made with oils showed firmer texture than ones made with animal fats. Ambrosiadis et al. (1996) conversely reported that replacing the pork fat in beef frankfurters with oils yielded lower textural firmness.

The present study investigated the effect of different cooking regimes (slow ramp vs rapid one- or two-step heating) on fat/water retention and rheological properties during and after cooking of high fat meat gels. Rendered animal fat (lard) was compared to soy oil in these formulations to determine if differences in gel structure due to heating rate or regime might thereby be better revealed.

2. Materials and methods

2.1. Materials

Boneless skinless chicken breast meat as a lean meat source was purchased from a local chicken processor (Pilgrim's, Sanford NC), packaged in ~3.5 kg portions in freezer bags and frozen at −20 °C until use (<-5 months). Frozen chicken was thawed at 4 °C for at least 12 h before the trimming of visible fat and connective tissue. Pork fat, in the form of lard, and vegetable oil (soybean oil) was obtained from a local grocery store packaged in sealed plastic containers and kept at 4 °C and room temperature (25 °C), respectively, until used.

2.2. Preparation of meat batters and paste

Finely comminuted batters were prepared by chopping thawed chicken (proximate analysis 23.21% protein, 1.34% fat, 69.45% water; at 51.17%, *w*/*w*) with water (24.83%, *w*/*w*), fat or oil (20%, *w*/*w*), salt (2%, *w*/*w*), sugar (1.7%, *w*/*w*), and tripolyphosphate (0.3%, *w*/*w*) in a Stephan UMC-5 vertical-cutter/mixer (Stephan Machinery Corp., Columbus, OH) under vacuum for 6 min at 25,000 rpm. The formulation is similar to that used in a leading brand of frankfurters. Final chopping temperature did not exceed 10 °C. Meat batters were vacuum-packaged in Cryovac B-series bags (Cryovac, Duncan, SC, U.S.A.) with a Multivac 8941 (Multivac, Allgau, Germany) and cooled to 5 °C. A corner of the bag was cut before placing into a manually operated sausage stuffer for extrusion of the batter into tared Teflon tubes (for microwave heating) or water-impermeable cellulose casings (for water bath heating), 1.9 cm inner diameter and 17.8 cm long. Tubes and casings were sealed at both ends with threaded end caps or by tying with string, respectively, and samples weighed before heating. All preparations of batters were conducted twice.

2.3. Heating regimes of gels

2.3.1. Conventional ramp heating process

Batter-filled cellulose casings were immersed and cooked in a programmable water bath (Neslab Instruments Inc., Portsmouth, NH) from 5 to 70 °C at the rate of 0.5 °C/min, to simulate a conventional smokehouse process. Product temperature was monitored with a thermocouple inserted into the geometrical center of the cylindrical gels.

2.3.2. Microwave cooking

Filled Teflon tubes were rapidly microwave heated at 100 °C/min in an Industrial Microwave Systems (IMS, Morrisville NC) focused (equal energy distribution) chamber (custom built for this experimentation; Riemann et al., 2004) to endpoint temperatures of 70 °C by one of the two processes: one-step (directly to 70° and held for 20 min) or two-step (firstly to 50 °C and isothermally held for 30 min, secondly to 70 °C and held for 20 min). 300 W and 150 W power settings were used for rapid heating and isothermal holding, respectively. Immediately upon completion of the heating step, all gels were quickly removed from tubes or casings, any released liquid remaining on gel surfaces was removed by wicking with filter paper, and weighed. Gels were then immediately placed in plastic bags, evacuated and sealed, and immersed into an ice–water bath for cooling.

2.4. Rheological properties of pastes/gels

2.4.1. Fracture testing of cooked, cooled gels and commercial products

Both a commercial product (Classic wieners™ by Oscar Mayer, Madison, WI) and cylindrical gels, prepared by heating in tubes in a water bath or microwave applicator and ice bath cooling, were held overnight under refrigeration, and subsequently cut into specimens 2.54 cm long, each end of which was glued to plastic disks (Gel Consultants Inc., Raleigh N.C.) using an instant adhesive. Capstan-shaped samples were milled from each specimen to 1 cm minimum diameter on a milling machine (Gel Consultants Inc.), wrapped in plastic wrap (to prevent moisture loss), and brought to room temperature before torsion testing. For testing, gel specimens were vertically mounted and twisted to the point of fracture at 2.5 rpm on a Hamann Torsion Gelometer (Gel Consultants Inc., Raleigh N.C.). Stress (kPa) and strain (dimensionless) at fracture were calculated with the manufacturer software for each sample, corresponding to the strength and deformability of the gels, respectively (Hamann, Amato, Wu, & Foegeding, 1990). Each variable has 6 replicates for data analysis.