Meat Science 83 (2009) 563–570

Contents lists available at ScienceDirect

Meat Science

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

Ohmic heating of meats: Electrical conductivities of whole meats and processed meat ingredients

Markus Zell, James G. Lyng *, Denis A. Cronin, Desmond J. Morgan

School of Agriculture, Food Science and Veterinary Medicine, College of Life Sciences, University College Dublin, Belfield, Dublin 4, Ireland

ARTICLE INFO

Article history:
Received 6 April 2009
Received in revised form 22 June 2009
Accepted 12 July 2009

Keywords:
Ohmic heating
Electrical conductivity
Meat formulation ingredients
Fibre direction

ABSTRACT

The ohmic heating rate of a food is highly influenced by its electrical conductivity (σ). A survey of σ values of commonly used meat ingredients when dispersed as 5% (w/w) aqueous solutions/suspensions was undertaken. A subset was further investigated at typical usage levels in solution/suspension, and/or when incorporated into beef blends, while σ of selected cuts from five meat species (beef, pork, lamb, chicken and turkey) was also measured. Measurements were made from 5 to 85 °C and showed a linear increase in σ values with increasing temperature. In processed beef, addition of sodium chloride and phosphate (P22) caused a significant increase in σ which in turn would lead to an increase in ohmic heating rates. Furthermore, whole meats with lower endogenous fat or processed meats with the least added fat displayed higher σ and reduced ohmic heating times. In beef maximum σ was observed when fibres were aligned with the current flow.

1. Introduction

The effectiveness of ohmic heating is markedly influenced by the composition and physical properties of the food to be heated. The latter include the electrical conductivity (σ), thermal conductivity (k) and specific heat capacity (Cp). Of these σ is the main factor in an ohmic heating process (Halden, de Alwis, & Fryer, 1990) and is directly proportional to the resultant rate of ohmic heating (Palaniappan & Sastry, 1991). De Alwis, Halden, and Fryer (1989) postulated that ohmic heating is most satisfactory for products having σ values in a range of 0.01–10 S/m, with optimum efficacy in the range 0.1–5 S/m.

Due to their potential influence on ohmic heating, knowledge of σ of meats and non-meat ingredients is essential in the formulation of meat products destined for ohmic heating. In raw meats the intrinsic levels of electrically conductive materials are sufficient to allow ohmic heating but σ can be dramatically altered by the nature of the ingredients added.

In recent years, several studies of the thermophysical properties of meat products and also their behaviour during ohmic heating have been published. Marcotte, Taherian, and Karimi (2008) presented data for thermophysical properties of various meat emulsions; however, most of these measurements were performed at a limited number of temperatures (20, 40, 60 and 80 °C). Sarang, Sastry, and Knipe (2008) also measured σ values of different meat cuts during ohmic heating using a small scale ohmic heating cell. Shirsat, Lyng, Brunton, and McKenna (2004b) reported that addition of lean to fat increased the overall conductivity.

For liquid-particulate systems the effects of structural influences on ohmic heating (e.g. particle orientation) have been well established (De Alwis & Fryer, 1990; Sastry & Palaniappan, 1992). Furthermore, in a review by McKenna, Lyng, Brunton, and Shirsat (2006) it was noted that for larger particles (15–25 mm) their orientation relative to the electrical field has a significant influence on electrical properties and on the relative heating rates of the phases. While Brunton, Lyng, Zhang, and Jacquier (2006) described the effect of muscle fibre direction on dielectric properties of beef *biceps femoris* at room temperature, there is no specific information available on the effect of muscle fibre direction during ohmic heating. Ohmic heating has proved successful in heating meat emulsion and meat batters (Shirsat, Brunton, Lyng, McKenna, & Scannell, 2004a; Piette et al., 2004). Although some data has been published on dielectric properties of meat ingredients (Lyng, Zhang, & Brunton, 2005) and also a limited amount on σ of meats and ingredients (Shirsat, Lyng, Brunton, & McKenna, 2004c) more information is required to establish how the interactions of these ingredients within a meat matrix impact on σ and on subsequent ohmic heating rate.

Therefore, the objective of this study was firstly to compare σ values of non-meat ingredients in solution/suspension and when incorporated in a meat product at typical usage levels. The influence of fat incorporation was also measured. For comparison σ values of a range of raw meat products were measured. The final

* Corresponding author. Tel.: +353 1 7167710; fax: +353 1 7161149.
E-mail address: james.lyng@ucd.ie (J.G. Lyng).

0309-1740/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.meatsci.2009.07.005

aim was to investigate the influence of fibre orientation and salt injection on σ of whole beef muscle during ohmic heating process.

2. Materials and methods

2.1. Sample preparation

2.1.1. Non-meat ingredients

Aqueous solutions or suspensions (5% w/w) of a range of non-meat ingredients (Table 1), used in the manufacture of meat products, were prepared by dissolving or dispersing 10 g of each ingredient in 190 g of distilled deionised water. The preparations were stirred using a mechanical stirrer (Model No. HB502, Bibby Sterilin Ltd., UK) at speed 2 to ensure complete dispersion. Aqueous solutions of selected ingredients were also prepared at levels typical of those used commercially (Table 1).

2.1.2. Meat

Five different fresh meat cuts (beef (*Semitendinosus*), pork (loin), lamb (leg), chicken (breast) and turkey (breast)) were procured from a local butcher (O'Mahony Meats Ltd., Coolock, Ireland) and frozen at −20 °C until used. The meat was defrosted overnight and, following fat trimming, cylindrical subsamples (approx. 58 g, 50 mm in length and 36 mm in diameter) were prepared using a custom made cork borer. The resulting samples were wrapped in cellophane, transferred to a plastic bag and held at 4 °C for at least 1 h to ensure temperature equilibration.

Further samples of beef were injected with a 3% salt solution and tumbled as described by Zell, Lyng, Cronin, and Morgan (2009). Subsequently, the tumbled meat was prepared as described above.

2.1.3. Preparation of lean beef for fibre direction analysis

Beef *Semitendinosus* muscle was chosen due to its uniformity of fibre direction. Samples (dimensions as above) were prepared in perpendicular and parallel directions to the muscle fibres and maintained at 4 °C until required.

2.1.4. Preparation of meat/ingredient blends

Lean beef meat (8 kg) was ground through a plate mincer with 3.5 mm diameter holes (Model No. TSE, Tritacarne, Omas, Italy). Subsequently, 500 g batches of the minced meat were blended

Table 1
Electrical conductivity (σ) values of 5% (w/w) and of typical usage levels % (w/w) aqueous solutions or dispersions measured using an electrical conductivity probe and an ohmic cell.

Ingredient	Levels (% w/w)	Electrical conductivity σ (S/m)				Time[a] (s)
		Probe		Cell		
		25 °C	80 °C	25 °C	80 °C	
Deionised water	NA	0.001	0.003	NA	NA	NA
Glucose	5	0.007	0.018			
Fructose	5	0.008	0.021			
Sucrose	5	0.013	0.031			
Sucrose	4	0.013	0.031	0.011	0.044	2372
Antioxidant BHA	5	0.016	0.042			
Lactose	5	0.022	0.059			
Potato starch	5	0.022	0.051			
Potato starch	4	0.015	0.046	0.017	0.049	1346
Wheat gluten	5	0.055	0.119			
Wheat gluten	0.15	0.017	0.043	0.016	0.051	1457
Wheat flour	5	0.091	0.197			
Wheat flour	3	0.061	0.139	0.053	0.127	928
Sodium caseinate	5	0.143	0.382			
Whey protein	5	0.147	0.374			
Soya protein isolate	5	0.165	0.404			
Soya protein isolate	1	0.054	0.127	0.047	0.121	947
Rusk	5	0.189	0.397			
Glucanolactone	5	0.222	0.539			
Soya concentrate	5	0.297	0.716			
Carrageenan	5	0.427	1.138			
Sodium ascorbate	5	1.118	2.418			
Sodium ascorbate	0.01	0.017	0.061	0.019	0.075	1093
MSG	5	1.289	2.97			
Red2G	5	1.689	3.58			
Sodium benzoate	5	1.828	5.14			
Tripolyphosphate	5	2.523	5.723			
Potassium sorbate	5	2.623	6.479			
Potassium sorbate	0.26	0.157	0.384	0.155	0.377	324
Phosphate (P22)	5	2.88	6.58			
Phosphate (P22)	3	1.794	4.351	2.066	4.339	19
Disodium phosphate	5	3.525	8.425			
Sodium nitrite	5	4.691	10.873			
Sodium nitrite	0.015	0.014	0.038	0.014	0.044	1877
Sodium nitrate	5	4.842	11.54			
Sodium nitrate	1.7	1.722	4.104	1.912	4.203	20
Sodium sulphite anh.	5	4.873	11.867			
White pudding spice	5	5.695	13.497			
White pudding spice	2.5	2.980	6.486	3.007	6.541	14
Sodium chloride	5	7.628	17.544			
Sodium chloride	1.5	2.725	6.172	2.78	5.973	16
Sodium chloride	2.5	4.29	9.25	4.35	9.07	10

[a] Time taken to ohmically heat the solutions from 25 to 80 °C; NA, not detectable.