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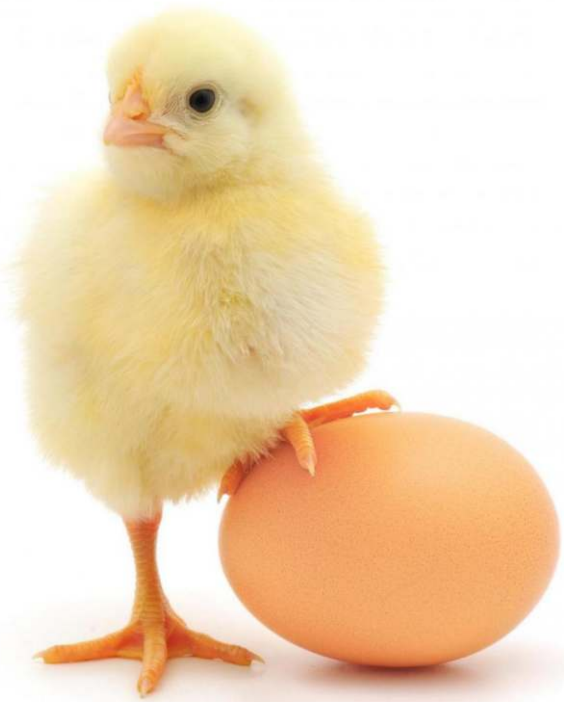

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Measurement of Dielectric Properties of Intact and Ground Broiler Breast Meat over the Frequency Range from 500 MHz to 50 GHz

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Abstract: The dielectric properties of food greatly influence its interaction with Radio Frequency (RF) and Microwave (MW) electromagnetic fields and subsequently determine the absorption of microwave energy and consequent heating behavior of food materials in microwave heating and processing applications. Microwave heating is usually recommended for further processed meats to reduce cooking losses. Ground muscle is a common ingredient in further processed meats. The objective of this study was to investigate the differences in dielectric properties between broiler whole muscle and ground muscle over a broad frequency range of 500 MHz to 50 GHz and to examine any correlations between meat functionality and the dielectric properties of the muscle. Dielectric properties were obtained utilizing an Agilent 85070E open-ended coaxial-line probe connected to an N5230C PNA L-Network Analyzer. Measurements were collected at 501 frequencies on a logarithmic scale from 500 MHz to 50 GHz on whole and ground chicken breast meat. Color, pH and water holding capacity were also measured. Ground muscle exhibited lower dielectric properties than the whole muscle overall ($p<0.05$). Dielectric properties from whole muscle showed no apparent correlations with quality parameters. However, the dielectric properties of ground muscle had a stronger relationship with the sample's water holding capacity ($p<0.05$).

Key words: Dielectric properties, microwave heating, ground muscle, water holding capacity, chicken breast meat

INTRODUCTION

Physical properties of foods provide essential data to the food industry and can be used in the design, installation, operation and control of processes, plant and equipment used in food processing (Lyng *et al*., 2005). Dielectric properties of foods are the electrical properties which strongly influence the temperature distribution of food during Radio Frequency (RF) and Microwave (MW) heating (Metaxas and Meredith, 1983). The dielectric properties are represented by $\varepsilon^* = \varepsilon' - j\varepsilon''$, where ε' is the dielectric constant and ε'' is the dielectric loss factor. The dielectric constant reflects the material's ability to store energy while the dielectric loss factor represents the energy dissipated in the material in the form of heat (Hasted, 1973; Von Hippel, 1954; Metaxas and Meredith, 1983). The dielectric properties of food greatly influence its interaction with the RF and MW electromagnetic fields (Nelson and Datta, 2001; Zhang *et al*., 2007) and subsequently determine the absorption of microwave energy and consequent heating behavior of food materials in microwave heating and processing applications (Nelson and Datta, 2001).

Microwave heating utilized in the cooking of meat is an extremely rapid process and is therefore usually recommended for further processed meats. Many further processed meat products utilize ground muscle and unlike less tender cuts, requires shorter cooking times to reduce cooking losses (Aberle *et al*., 2001). Further processed meat products account for approximately 50% of the broiler market (National Chicken Council, 2010). With an increase in the amount of further processed products being marketed, it is essential to understand the different properties that affect meat functionality in complex ready-to-eat meat products (Bianchi *et al*., 2005).

The major poultry meat quality attributes are appearance, texture, juiciness, flavor and functionality (i.e. water holding capacity, water binding capacity and emulsion capacity) (Fletcher, 2002). Much research has focused on the influences of biochemical reactions involved in the conversion of whole muscle to meat upon quality while little research has investigated the changes that occur in ground muscle (Hamm, 1977). Hamm (1977) reported that properties favorable for meat processing such as higher water holding capacity and better fat emulsification were retained by freezing prerigor ground muscle. The relationship between ground muscle and quality characteristics can provide practical knowledge in poultry processing. Grinding meat immediately after slaughter and eliminating intermediate refrigeration can lead to reduced manufacturing costs (Hamm, 1977).

The most common frequencies studied on dielectric properties of food involve those at 27.12 MHz (most

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commonly used RF band), 915 MHz (used for industrial MW processing and tempering) and 2450 MHz (used for catering/consumer MW heating) (Nelson and Datta, 2001).

The objective of this study was to investigate the differences in dielectric properties between broiler whole muscle and ground muscle over a much broader frequency range of 500 MHz to 50 GHz. In addition, correlations between meat functionality and the dielectric properties of the muscle were investigated.

MATERIALS AND METHODS

Sample collection: Boneless, skinless, broiler breast filets were obtained from a local commercial processing plant. Samples were collected at 24 hrs *postmortem* and put on ice for transport to Russell Research Center for analysis.

Color and pH measurements: L* values were determined on the right ventral pectoralis major using a Minolta Chroma Meter CR-410, Osaka, Japan. Color measurements were made on the medial portion of the filet void of any color defects such as bruises, blood spots or discolorations. Color values were reported as the average value of triplicate measurements. The pH measurements were performed with a spear tip Hannah pH meter (Hannah Instruments, Van Nuys, CA) designed for meat samples. All measurements were taken 24 hrs postmortem.

Water Holding Capacity (WHC): WHC was determined as described by Barbut (1993) with some minor modifications. All skin and visible fat were removed from the breast meat. Approximately 75 to 100 grams of the medial portion of the breast meat was chopped for approximately 20 sec in a small chopper to mince the meat. A 10 g aliquot of the chopped muscle was mixed with 16 ml of 0.6 M NaCl and then incubated for 30 min at 4°C. Samples were then centrifuged at 7000 g at 4°C for 15 min and the supernatant was decanted. WHC was defined as the portion of fluid retained by the sample:

$$\frac{16\text{ ml} - (\text{amt of decanted supernatant})}{16\text{ ml}} \times 100 = \text{WHC (\%)}$$

Dielectric properties measurement: Dielectric properties were obtained utilizing a Hewlett-Packard 85070E open-ended coaxial-line probe connected to an N5230C PNA L-Network Analyzer through a flexible coaxial cable. Measurements were collected at 501 frequencies on a logarithmic scale from 500 MHz to 50 GHz. Prior to sample measurements, the open-ended coaxial-line probe connected to the analyzer was calibrated with measurements on air, a short-circuit block and glass-distilled water at 25°C (Nelson *et al.*, 1997). Measurements were performed on whole muscle filets and ground meat from broilers equilibrated to 25°C±1. The dielectric constant and loss factor were calculated from measurement of the reflective coefficient utilizing the Agilent Technologies 85070E Dielectric Probe Kit Software.

Measurement procedures: For each whole muscle filet, measurements were taken on the dorsal surface at the cranial area. The sample was placed on a flat platform surface sitting atop a laboratory jack used to raise the sample for measurements with an Agilent performance probe. For measurement of the ground meat samples, approximately 4g of minced meat were placed in a 10 ml glass beaker. Samples were smoothened at the top with a small spoon spatula to ensure a flat surface. Measurements were made in triplicate on the ground meat surface. All measurements were taken on samples equilibrated to 25°C±1.

Data were analyzed with the General Linear Model (GLM) procedure of SAS software and means were compared using the Least Significant Difference (LSD) test with a significance level of α = 0.05. The Pearson Product Moment Correlation Coefficients were also determined to see if any of the quality parameters measured had any significant relationships with the dielectric properties of the meat (SAS 9.2, SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

The descriptive data of all the samples is provided in Table 1 and shows that a diverse population was used in the study. The mean pH value of the breast meat samples was 5.89 and the mean value for L* value for all breast meat was 58.35 with a maximum value of 63.60 and a minimum value of 52.04. The water holding capacity ranged from 2.5% to 23.7% with a mean value of 7.42%. The relationship between muscle pH, color and meat quality in red meat species is well established. Although the relationship between poultry meat color and pH has also been well documented, the relative influence on poultry meat quality is not as well established as in the extremes of PSE and dark, firm and dry conditions in pork and beef, respectively (Qiao *et al.*, 2001).

The difference in mean spectra for whole and ground muscle over the frequency range from 500 MHz to 50 GHz can be seen in Fig. 1. When examining the properties separately, a significant difference can be clearly seen between the dielectric constants of the whole and the ground muscle (Fig. 1a). This difference was confirmed through use of the LSD means test at several frequencies which are shown in Table 2. There was a significant difference (α = 0.05) between means at the following frequencies: 500 MHz, 900 MHz, 3 GHz, 15 GHz, 30 GHz and 50 GHz. Ground muscle exhibited a lower dielectric constant than the whole muscle. The dielectric constant is associated with the ability of a

Table 1: Descriptive data for sample set

Quality parameter	N	Mean	Std Dev	Range	Max	Min
L*	56	58.35	2.50	11.56	63.60	52.04
a*	56	11.39	1.19	5.27	13.83	8.56
b*	56	21.12	2.54	11.12	27.37	16.25
pH	56	5.89	0.18	0.84	6.32	5.48
WHC (%)	56	7.42	3.72	21.20	23.70	2.50

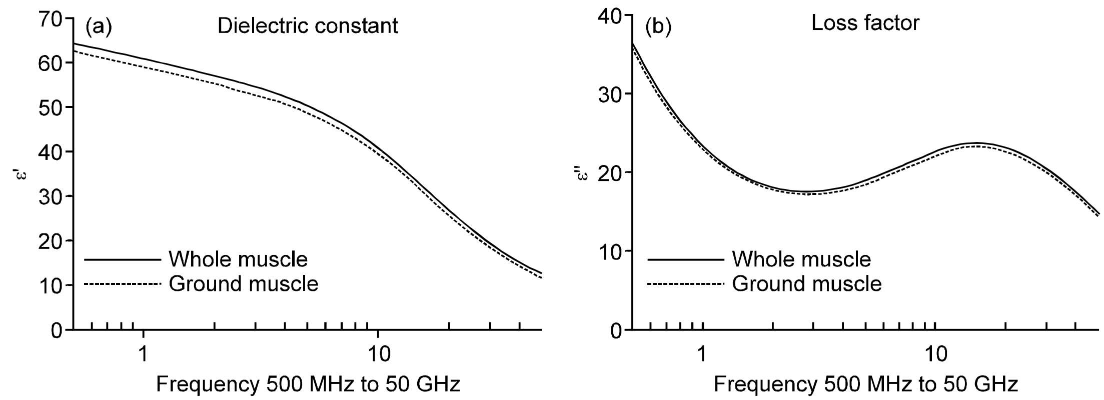

Fig. 1: Dielectric properties of the mean values for whole and ground muscle: (a) dielectric constant (ε') (b) dielectric loss factor (ε''). Measurement of dielectric properties of whole and ground chicken breast meat over the frequency range from 500 MHz to 50 GHz

Table 2: LSD mean differences at selected frequencies for dielectric constant (ε')

Frequency	N	Mean	Std Dev	Std Err
500 MHz				
Whole muscle	56	64.31^{a}	2.15	0.29
Ground muscle	56	62.47^{b}	1.42	0.19
900 MHz				
Whole muscle	56	61.30^{a}	2.17	0.29
Ground muscle	56	59.43^{b}	1.42	0.19
3 GHz				
Whole muscle	56	54.45^{a}	2.02	0.27
Ground muscle	56	52.55^{b}	1.34	0.18
15 GHz				
Whole muscle	56	32.75^{a}	1.25	0.17
Ground muscle	56	31.49^{b}	0.92	0.12
30 GHz				
Whole muscle	56	19.30^{a}	0.59	0.08
Ground muscle	56	18.21^{b}	0.86	0.11
50 GHz				
Whole muscle	56	12.71^{a}	0.44	0.06
Ground muscle	56	11.71^{b}	0.85	0.11

$^{a-b}$Means within column with differing superscripts are significantly different from each other ($\alpha = 0.05$)

Table 3: LSD mean differences at selected frequencies for dielectric loss factor (ε'')

Frequency	N	Mean	Std Dev	Std Err
500 MHz				
Whole muscle	56	36.42^{a}	2.62	0.35
Ground muscle	56	35.69^{a}	1.20	0.16
900 MHz				
Whole muscle	56	24.63^{a}	1.58	0.21
Ground muscle	56	24.20^{a}	0.73	0.10
3 GHz				
Whole muscle	56	17.60^{a}	0.83	0.11
Ground muscle	56	17.22^{b}	0.43	0.06
15 GHz				
Whole muscle	56	23.76^{a}	1.13	0.15
Ground muscle	56	23.22^{b}	0.70	0.09
30 GHz				
Whole muscle	56	20.38^{a}	0.96	0.13
Ground muscle	56	19.97^{b}	0.62	0.08
50 GHz				
Whole muscle	56	14.71^{a}	0.66	0.09
Ground muscle	56	14.36^{b}	0.50	0.07

$^{a-b}$Means within column with differing superscripts are significantly different from each other ($\alpha = 0.05$)

material to store energy. The dielectric loss factor describes energy dissipation in the material as a form of heat (Hasted, 1973; Von Hippel, 1954; Metaxas and Meredith, 1983). Differences were not as pronounced in the loss factor over the entire frequency range (Fig. 1b). The LSD mean tests (Table 3) confirmed that no significant differences were seen at the lower frequencies. However, at the higher frequencies, 3 GHz and above, significant differences did occur. The differences seen in dielectric properties of whole and ground muscle could be attributed to the amount of free and bound water in the samples and the impact of grinding on the samples. Water constitutes approximately 75% of muscle and exists in three forms: bound, immobilized and free. Bound water is water that is tightly bound to muscle proteins and remains bound despite the amount of physical force exerted upon the muscle. It can account for 4 to 5% of the water in muscle. Immobilized water is located between the thick and thin filaments. It accounts for approximately 10-15% of the

Table 4: Correlation factors between color, pH, pickup % and frequencies. P-values listed below correlation factors

	Frequency					
	500 MHz	900 MHz	3 GHz	15 GHz	30 GHz	50 Ghz
ε'						
pH	-0.31	-0.30	-0.30	-0.28	-0.25	-0.12
	0.0210	0.0244	0.0268	0.0385	0.0593	0.3722
L*	0.29	0.31	0.32	0.38	0.41	0.33
	0.0297	0.0198	0.0172	0.0044	0.0017	0.0127
WHC	-0.49	-0.49	-0.48	-0.43	-0.32	-0.32
	0.0001	0.0001	0.0002	0.0010	0.0147	0.0146
ε''						
pH	-0.20	-0.20	-0.24	-0.20	-0.19	-0.33
	0.1497	0.1431	0.0771	0.1300	0.1590	0.0132
L*	0.09	0.10	0.14	0.11	0.11	0.30
	0.5090	0.4560	0.3046	0.4014	0.4174	0.0268
WHC	-0.39	-0.41	-0.50	-0.36	-0.29	-0.33
	0.0027	0.0019	0.0001	0.0060	0.0291	0.0129

water in the muscle and its existence depends upon the amount of physical force exerted upon the muscle. The remaining water exists as free water which is located in the extracellular spaces of the muscle and held loosely by capillary forces. This water is easily lost when mechanical or physical forces are applied (Aberle *et al.*, 2001; Hui, 2006; Lawrie, 1998). Mashimo *et al.* (1987) confirmed the existence of two Debye absorption peaks around 20 GHz and 100 MHz in several biological materials and attributed the peaks to be associated with free and bound water, respectively.

Pearson Product Moment Correlation Factors suggested a possible relationship between water holding capacity and dielectric properties of ground muscle at selected frequencies (Table 4). The correlation factors between the dielectric constant and water holding capacity decreased as the frequency increased. The relationship between the dielectric loss factor and water holding capacity had the reverse effect in which the correlation factors increased until it reached a peak at the frequency of 3 GHz. Water holding capacity can be influenced by a number of biochemical factors such as postmortem events including rate and decline of pH; proteolysis and protein oxidation (Huff-Lonergan and Lonergan, 2005). The principle determinant in water holding capacity is the filament lattice spacing which is determined by the following: electrostatic repulsive forces, restraining forces by structural proteins and chemical potential of the water in the fibers (Kristinsson and Hultin, 2003).

In summary, analysis of dielectric spectra showed differences in mean spectra of whole and ground muscle. Ground muscle exhibited lower dielectric properties than the whole muscle overall. The differences in the dielectric constants for whole and ground muscle were clearly seen at all frequencies. However, differences in the dielectric loss factors at lower frequencies were not as evident between whole and ground muscle. Correlations between the dielectric properties of ground muscle and water holding capacity warrant further investigation of the factors influencing the relationship.

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