Experimental Determination of the Electrical Resistivity of Beef*

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ABSTRACT

Electrical resistivity properties of beef were investigated. The resistivity behavior under three frequencies of 1, 10 and 100-kHz, several temperatures (5, 10, 15, and 20 ^{0}C), different length and cross-sectional areas (width: 7 cm, two depths: 3 and 5 cm, and four lengths:7, 11, 15, and 19 cm) were determined. The electrical series circuit was found to be adequate to measure the resistivity properties of beef. Samples with warmer temperatures offered much less resistance and the resistivity values obtained at temperatures 5 ^{0}C and below were not consistent. Increasing temperature had a significant effect on the resistivity values of beef ($p < 0.05$). Increase in frequency did not have any significant effect on the resistivity properties of beef ($p > 0.05$). It was observed that resistivity was higher across the myofiber axes than along the myofiber axes. However, there was no significant difference between the fiber directions in terms of resistivity ($p > 0.05$). The mean resistivity of beef at 20 ^{0}C for across the myofiber and along the myofiber directions was found to be 365.42 Ohms.cm and 346.67 Ohms.cm, respectively.

Keywords: Electrical resistivity, beef, anisotropy

1. INTRODUCTION

Electric treatments are among the many novel food preparation processes and/or conservation methods used in recent years (Ranalli et al., 2002). It has been reported that electric current flowing through meat decreases the microbial count of carcasses by preventing cold shortening and improving quality parameters such as color, tenderness (shear force), and flavor (Cetin and Topcu, 2009). A number of studies reported the use of electrical current for reduction of microorganisms on meat surfaces (Bawcom et al., 1995; Tinney et al., 1997; Saif et al., 2006; Mahapatra et al., 2008). Electrical stimulation of carcasses has been used to improve meat quality and guard against cold shortening (Bouton et al., 1978) and recent studies have verified the tenderization effect of electrical stimulation even at low voltage (Kim et al., 2007; Li et al., 2006). The increase in the uses of electroprocessing of foods requires the knowledge of electrical properties and their effects on processing (Icier and Baysal, 2004). Since 1980, the electrical properties of muscle have been investigated to determine or predict meat quality (Lee et al., 2000). Thus electrical properties of meat have become an important area of research interest in order to develop adequate process to ensure quality and safety of meat products, particularly, automated mass production systems, commonly used in industries (Saif et al., 2004_a; Saif et al., 2004_b, Mahapatra et al., 2007). The electrical properties of beef are of great importance in processing beef with pulsed electric fields, ohmic heating, and microwave heating. Since there is a strong demand from meat industry for use of nondestructive methods for assessing meat quality in general and in particularly meat tenderness (Lepetit et al., 2002), electrical properties could be used for quality evaluation.

Electrical conductivity is the ability of a substance to conduct electric current. Resistivity is the inverse of conductivity and is linked with impedance. Electrical impedance is the combined opposition to the flow of current offered by the resistive, capacitive, and inductive components (Byrne et al., 2000). Electrical resistivity of a material is defined as the resistance to the current passing across a 1-cm cube of material (Tekin and Hammond, 2000). An understanding of electrical resistivity behavior of beef would enable us to optimize the electrical parameters that could be used in designing appropriate techniques to apply electrical stimulation to inactivate harmful pathogens that cross-contaminate the meat in the processing line, and simultaneously accomplishment of the tenderization of meat. However, a very few studies have been conducted on the electrical resistivity of beef with particular reference to varying temperature regimes and sample dimensions. The objective of the current study was to determine and evaluate the electrical resistivity properties of beef with respect to varying temperatures, frequencies, length and cross-sectional areas.

2. MATERIALS AND METHODS

Lean retail cuts (bottom round roast) were procured from a local meat store (Peacock Meats, Warner Robins, GA). Sample dimensions were chosen carefully to obtain shape factors (φ) in the range of 0.2 to 0.9. The shape factor was defined by $\varphi = l/A$ (where l is the length and A is the cross-sectional area of the beef sample). The beef samples were stored in a freezer at -20 ^{0}C for about a week. Frozen beef samples were allowed to defrost overnight in the refrigerator set at 4 ^{0}C. The resistivity behavior of beef under three frequencies (1, 10, and 100-kHz), several beef cut dimensions (two depths: 3 and 5 cm; four lengths: 7, 11, 15, 19 cm; and one width: 7 cm), two fiber directions (parallel and transverse), and several temperatures (5, 10, 15 and 20 ^{0}C) were investigated. Low voltage square-wave treatments were applied (18 V, ac). The internal temperatures were measured at two different places of the sample using a thermocouple thermometer (OM-400 Multichannel data logger, Omega, Stamford, CT). Two thermocouples were inserted into the sample through the top surface of the sample and were in the sample during the experimentation process. A power supply system including a function generator (Function Generator Model 4071A, 10 MHz, BK Precision, Placentia, CA) and power modulation unit (Bipolar Operational Amplifier, 36V-12A, KEPCO, Flushing, Inc., NY), was used. Square waveform and desired magnitude of voltage were set through the function generator. Both the input and output voltage were monitored through an oscilloscope (Model 221A, Tektronix, Inc., Beaverton, OR). The current passing through sample and the output root mean square (RMS) voltage across the beef sample were measured with a digital multimeter (Dual Display Digital Multimeter Model gdm 8245, GM Instrument Co., Taipei, Taiwan). The schematic of the circuit diagram is shown in Figure 1. The system has been described in detail elsewhere (Saif et al., 2004_b). Two plates of platinum were used as electrodes (5 cm x 5 cm).

For the determination of resistivity the current flow through the sample and voltage drop across it were measured (Saif et al., 2004_b). The frozen beef samples were gradually thawed to room temperatures during the experimentation. The sample temperature was allowed to increase and the temperature, current flow and voltage drop across the samples were measured at every hour on the day of the experiment.

2.1 Resistivity of Beef

Impedance across the beef sample was calculated from the RMS values by measuring the current and voltage and applying Ohms' law for ac (Valkenburgh, 1992). Impedance values were plotted against the corresponding shape factors and straight lines were fitted to the data. Resistivity for the beef sample was obtained from the straight line almost passing through the origin, following the relation (Saif et al., 2004_b):

$$Z = \rho\varphi \tag{1}$$

Where, Z = impedance (Ohms), ρ = resistivity (Ohms.cm), and φ = shape factor (cm^{-1}).

The experiments were replicated five times and the mean values of resistivity were obtained. Data were analyzed using the general linear model (GLM) procedures of the Statistical Analysis System version 9.1 (SAS, 2003). Differences were defined as significant at $p \leq 0.05$.

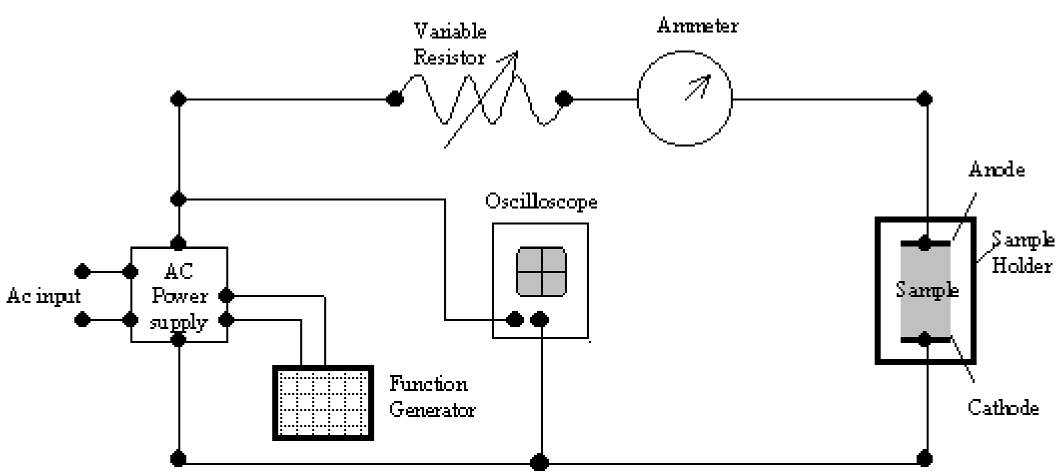

Figure 1. Schematic circuit diagram for the measurement of the impedance of the beef sample (Saif et al., 2006).

3. RESULTS AND DISCUSSION

3.1 Effect of Fiber Direction on Resistivity

The mean resistivity values across and along the muscle fiber direction of beef are presented in Table 1. Beef is electrically anisotropic, which means that its electrical properties change depending on the direction of the electrical field in the sample. Resistivity across the muscle fiber was higher than along the fiber. Similar results were reported for beef (Swatland, 1980), chicken meat and pork chops (Saif et al., 2004$_a$) and goat meat (Saif et al., 2004$_b$).

Table 1. Mean resistivity values of beef, across and along the myofiber axes

Sample temperature, ^{0}C	Mean resistivity, Ohms.cm (± SE)	
	Across	Along
5	1390.99 (212.19)	918.99 (194.37)
10	526.74 (56.95)	468.92 (66.33)
15	399.86 (36.62)	387.83 (56.38)
20	365.42 (15.81)	346.67 (19.76)

The mean resistivity of beef at room temperature (20 ^{0}C) for across the myofiber and along the myofiber directions was found to be 365.42 Ohms.cm and 346.67 Ohms.cm, respectively. The resistivity of other muscle foods has been complied and presented in Table 2. Our results indicated that the resistivity across myofibers in beef was, on the average, about 18 percent higher than along the myofibers. However, the difference in the resistivity values between the two was not significant ($p > 0.05$). In a similar study, Saif et al. (2004$_a$) reported a difference of 23 percent for chicken breast meat and 30 percent for pork. The higher resistivity could be because of the presence of connective tissues, namely, collagen and the fat tissues, which were good insulator to the electricity (Saif et al., 2004$_a$).

The storage of beef samples at - 20 ^{0}C in a freezer for a week could have caused membrane injuries. As a result the intercellular and intracellular part of tissue could have been mixed causing the difference in resistivity along and across myofiber axes to decrease. In addition, the lack of homogeneity of beef samples and uniformity in fiber direction could have affected the resistivity values. A piece of beef with cut dimensions 19 x 5 x 7 cm and approximate volume of 665 cm^3 was a substantial piece of meat. It could be possible that the fibers did not run in a uniform fashion throughout the sample.

Table 2. Resistivity values of selected muscle food

Type of meat	Resistivity, Ohms.cm	Reference
Chicken	124 – 177.3	Saif et al., 2004_a
Goat	188 – 350.6	Saif et al., 2004_b
Pork	107 – 140	Saif et al., 2004_a
Pork	131.6 – 156.3	Shirsat et al., 2004

As expected, the resistivity was influenced by the length of the sample following the relation:

$$\rho = RA / l \tag{2}$$

Where, ρ = electrical resistivity or specific resistance (Ohm.cm), R = resistance (Ohms), A = cross-sectional area of sample (cm^2) and l = length of the sample (cm). Figure 2 shows a typical resistivity vs. sample length relationship. As the length of the sample was increased from 7 cm to 19 cm, the resistivity decreased.

Since the cross-sectional areas of beef samples (3 * 7 cm, and 5 * 7 cm) were larger than the cross-sectional area of the electrodes (5 * 5 cm), it could be possible that the electrical field was not homogeneous inside of samples and thus caused the change of resistivity with relation to sample length.

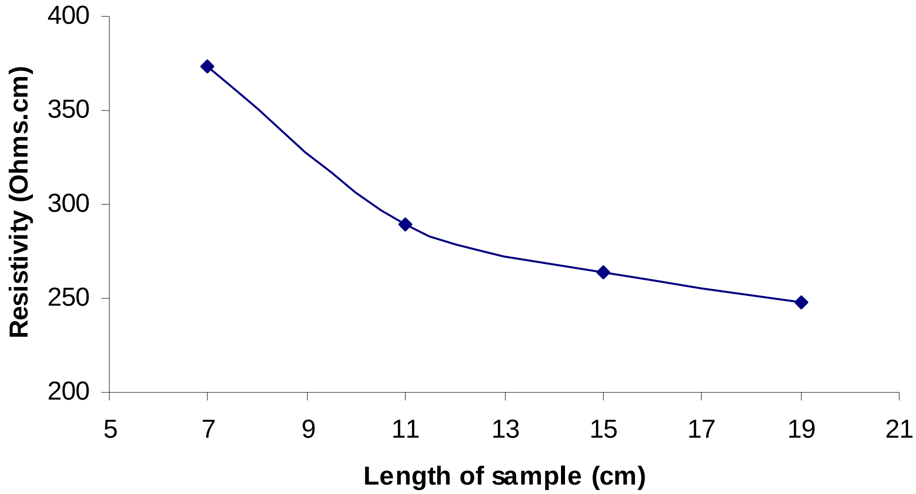

Figure 2. Resistivity of beef at 20 ^{0}C corresponding to length of the sample (depth: 3 cm, across myofiber).

3.2 Effect of Temperature on Resistivity

Effect of temperature on resistivity is shown in Figure 3. There were significant differences between temperatures in terms of beef resistivity ($p < 0.05$). Temperature is a critical factor because the flow of electricity is affected by temperature: there is much less resistance to the electrical flow with warmer temperatures (Marchello et al., 1999). The resistivity values obtained at temperatures 5 ^{0}C and below were not consistent. The unreliability of data measured below 5 ^{0}C could be due to the fact that the samples were not completely thawed or an uneven temperature distribution within the sample. Marchello et al. (1999) suggested that ice crystals formed in samples could create erroneous readings. Significant changes in the resistivity values could also occur because of cells or tissues moving from one physiological state to another (Grimnes and Martinsen, 2000).

The degree of thawing must have an effect on the resistivity. Since the samples were allowed to thaw in the apparatus and measurements were made each hour, samples might have lost moisture during the thawing time. Moisture loss would have changed sample condition which in turn would have influenced electrical properties.

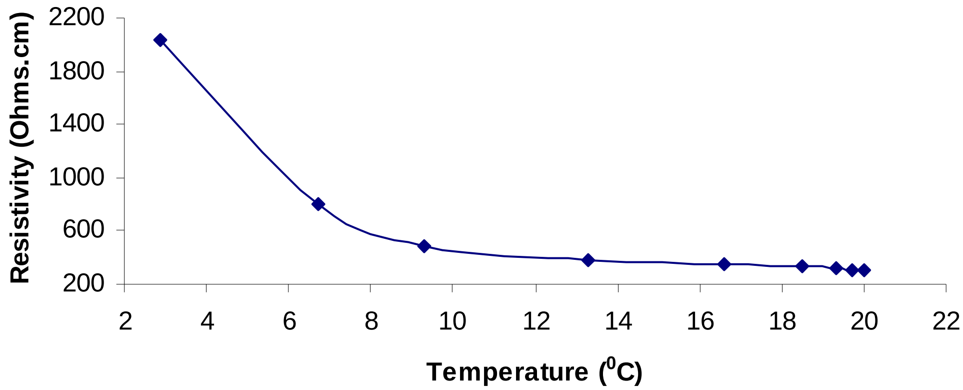

Figure 3. Effect of sample temperature on the resistivity (dimension: 19x7x5 cm, along myofiber).

3.3 Effect of Frequency on Resistivity

From our results, it was found that the frequency did not have any significant effect on the resistivity values ($p > 0.05$). In contrast, Saif et al. (2004_a; 2004_b) reported that the resistivity of chicken meat, pork chops and goat meat decreased with the increase in frequency. Swatland (1997) reported that a 10-kHz test current gave the most consistent resistance values for both beef and pork. However, Bodakian and Hart (1994) measured the conductivity of freshly slaughtered beef and commercial samples obtained from the supermarket in the frequency range of 1 Hz to 1 MHz and observed that the conductivity of commercial samples was nearly constant in that range. This could be possibly due to the gradual breakdown of the cellular structure of the beef and additional structural changes produced through freezing of meat.

4. CONCLUSIONS

The resistivity of beef decreased with increasing temperature. It can be concluded from this study that temperature was a critical factor and the resistivity values displayed a significant variation with temperature ($p < 0.05$). The resistivity across myofibers in beef was, on the average, about 18 percent higher than along the myofibers. However, there was no statistical difference between the two resistivity values ($p > 0.05$). The resistivity was also influenced by the length of the sample. It was found that the frequency did not have any significant effect on the resistivity values ($p > 0.05$).

The study potentially represented a relatively novel contribution as it presented electrical property data in the form of resistivity and accounted for temperature and sample dimensions.

Though there has been an upsurge in research in electroprocessing techniques, such as ohmic, radio frequency heating, and high voltage pulsed-electrical fields in recent years, the number of commercial applications for these technologies, particularly in the area of meat processing is still low. The accuracy in determination of electrical properties of muscle foods must be improved for its potential to be able to be realized.

5. ACKNOWLEDGEMENTS

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