Use of Dielectric Spectroscopy for Determining Quality Attributes of Poultry Meat

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Abstract. Use of dielectric spectroscopy for determining quality attributes of poultry meat was investigated at frequencies between 200 MHz and 20 GHz and temperatures ranging from -16 °C to 70 °C. Dielectric measurements were performed with an open-ended coaxial-line probe and a vector network analyzer. Samples were cut from chicken breast and placed in a temperature-controlled sample holder for the dielectric spectroscopy measurements. Also, for each chicken breast the pH and water holding capacity were measured. The frequency dependence of the dielectric properties of chicken breast indicates that ionic conduction is the dominant mechanism at the lower frequencies and there is a dipolar relaxation at about 10 GHz. Temperature dependence of the dielectric properties of chicken breast reveals a sharp increase of the dielectric constant and dielectric loss factor at 0 °C. This behavior is similar to that of water.

Keywords. Dielectric properties, frequency, temperature, dielectric spectroscopy, chicken breast meat, pH, water holding capacity.
Introduction

Dielectric properties of materials are intrinsic electrical parameters that characterize the interaction between the electric field of an electromagnetic wave and the material. Therefore, they represent the electrical signature of a given material. They are often represented by the complex entity known as the relative complex permittivity $\varepsilon = \varepsilon' - j\varepsilon''$, where $\varepsilon'$ is the dielectric constant and $\varepsilon''$ is the dielectric loss factor. Dielectric properties are dependent on frequency, temperature, and composition, in particular the amount of water in the material (Hasted, 1973). Knowledge of dielectric properties is important in radio-frequency and microwave heating applications (Metaxas and Meredith, 1983), remote sensing (Ulaby et al., 1986), and nondestructive sensing of physical properties of materials such as bulk density and moisture content of granular materials (Kraszewski, 1996; Trabelsi et al., 2000; Trabelsi et al., 1998; Trabelsi and Nelson, 2004). In recent years, attempts have been made to use dielectric properties for sensing quality attributes of materials (Nelson, 2006). For instance, Kent and Anderson (Kent and Anderson, 1996) investigated the use of dielectric properties to detect water added to chicken breast and in pork products (Kent et al., 2002). Also, dielectric properties were used to study effects of deboning time and muscle type of uncooked chicken breast meat (Zhuang et al., 2007).

Dielectric spectroscopy involves measurement of the dielectric properties over a broad frequency range (Nelson and Trabelsi, 2009; Nelson and Trabelsi, 2008) and can be used in many sensing applications related to quality and safety of food and agricultural products. It is the objective of work reported in this paper to determine the dielectric properties of chicken breast meat at frequencies from 200 MHz to 20 GHz and at temperatures from -16 °C to 70 °C and to study their correlation with physical properties such as water holding capacity and pH.

Materials and Methods

Dielectric Properties Measurements

Dielectric properties of chicken breast were measured with a Hewlett-Packard⁠¹ 85070B open-ended coaxial-line probe and an 8510C vector network analyzer (VNA) between 200 MHz and 20 GHz. The open-ended probe connected to the VNA through a high quality coaxial cable was calibrated with measurements on air, a short-circuit block, and glass-distilled water at 25 °C (Nelson et al., 1997). Settings were made to provide measurements at 51 frequencies on a logarithmic scale between 200 MHz and 20 GHz. A temperature-controlled stainless steel sample cup and water jacket assembly designed for the 85070B dielectric probe was used for the measurements (Nelson, 2003). The dielectric properties were calculated from measurement of the reflection coefficient at the active tip of the probe with Agilent technologies 85070D Dielectric Probe Kit Software.

Measurement Procedures

From each chicken breast, a 1.5-cm long cylindrical shaped sample was cut with a 21-mm diameter cork borer and then inserted into the stainless steel cup. The cup-water jacket

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¹ Mention of company or trade names is for purpose of description only and does not imply endorsement by the U.S. Department of Agriculture.
assembly was then raised to bring the sample into firm contact with the open-ended coaxial-line probe for the dielectric properties measurement. It is essential to adopt the same measurement routine whereby the pressure exerted by the probe on the sample is the same for each sample, because the dielectric properties are sensitive to changes in the density of the material at the tip of the probe.

First, dielectric properties of chicken breast samples were measured at 24 °C and then at temperatures ranging from -16 °C to 70 °C. For measurements with varying temperature, the sample temperature was changed through a Haake DC 10 water circulator filled with a mixture of water and ethylene glycol. Once the set temperature on the water circulator was reached, the chicken breast sample, inside the stainless steel cup, was allowed to equilibrate at that temperature for at least 10 minutes before the dielectric measurements were taken. Each chicken breast sample was characterized by its water holding capacity (WHC) and pH.

Results and Discussion

Figures 1 and 2 show variation of the dielectric constant and dielectric loss factor with frequency at 24 °C for chicken breast of similar water holding capacity (WHC) and variable pH values. They reveal that the dielectric properties are higher for higher pH and show clearly the effect of ionic conduction, which is dominant at lower frequencies. They also show a dipolar-type relaxation at higher frequencies, which is caused by the water contained in the chicken breast tissue (figure 2). However, the relaxation appears to be broader than that of liquid water indicating a range of relaxation frequencies rather than a single relaxation frequency of 19 GHz characteristic of liquid water at 25 °C (Hasted, 1973). This is further confirmed by the complex-plane representation of the dielectric properties (Cole-Cole plot) presented in figure 3. For each chicken breast sample, the plot consists of two distinct sections: a linear section corresponding to the lower portion of the spectrum where the dielectric response is dominated by ionic conduction and a section of a semicircle with its center below the ε′-axis which represents the broad relaxation taking place at higher frequencies and is characteristic of dielectric response of bound water (Trabelsi and Nelson, 2006). This is to be expected, since water inside the chicken breast meat is of bound form with possibly different degrees of binding.

Figures 4 and 5 show variation of the dielectric constant and dielectric loss factor with temperature at 2.936 GHz for chicken breast samples and distilled water. At low temperatures, dielectric properties of the chicken breast samples show a behavior similar to that of distilled water with a sharp increase around 0 °C. This is characteristic of phase change from solid to liquid water. At temperatures above 0 °C, dielectric constants of the different chicken breast samples are distinct and follow a trend similar to that of distilled water. However, they are less than those of water. In contrast, values of the dielectric loss factor of distilled water are at first greater than those of the chicken breast samples and then decrease rapidly with temperature to become less than those of chicken breast samples above 10 °C.
Figure 1. Dielectric constant of chicken breast samples as a function of frequency at 24 °C. The chicken breast samples had a water holding capacity of about 0.16 and different pH levels.

Figure 2. Dielectric loss factor of chicken breast as a function of frequency at 24 °C. The chicken breast samples had a water holding capacity of about 0.16 and different pH levels.
Figure 3. Complex-plane representation of the dielectric properties of chicken breast samples at 24 °C and frequencies ranging from 200 MHz to 20 GHz. The chicken breast samples had a water holding capacity of about 0.16 and different pH levels.
Figure 4. Dielectric constant of chicken breast samples, of indicated water holding capacity and pH, as a function of temperature at 2.936 GHz.

Figure 5. Dielectric loss factor of chicken breast samples, of indicated water holding capacity and pH, as a function of temperature at 2.936 GHz.
Conclusion

Measurement of the dielectric properties of chicken breast tissue over a broad frequency range revealed that it was possible to characterize each tissue sample according to its water holding capacity and pH. Also, the complex-plane representation of the dielectric properties of chicken breast samples indicated the presence of a broad relaxation that is typical of bound water with different degrees of binding. This was further confirmed with measurements over a wide temperature range.

Results presented in this study indicate that dielectric spectroscopy has potential for determining quality attributes of chicken breast meat such as water holding capacity and pH from measurement of their dielectric properties.

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References


