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Sugar and water contents of honey with dielectric property sensing

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ABSTRACT

The dielectric properties of pure yellow locust, jujube and rape flower honey and their water-adulterated products with water content from 18% to 42.6% were measured with open-ended coaxial-line probe technology and a network analyzer from 10 to 4500 MHz at 25 °C. Dielectric constants of pure honeys and water-added honey samples decreased monotonically with increasing frequency, and increased with increasing water content. Dielectric relaxation was evident in the dielectric loss factors. The critical frequency and the maximum loss factor increased with increasing water content. There were strong linear correlations between the dielectric constant and the total soluble solids and water contents. The linear coefficients of determination were higher than 0.995 from 650 to 960 MHz. The good linear correlations and the sufficient penetration depth >20 mm below 960 MHz, suggest that microwave dielectric properties could be used in developing sensors to determine sugar and water contents.

1. Introduction

Honey is a sweet, viscous, and natural complex liquid food product with sought after flavor. It is produced by honeybees from the nectar of flowers. Bee honey has significantly nutritional and medical benefits with readily available sugars, organic acids, various amino acids and some biological active components such as α-tocopherol, ascorbic acid, and flavonoids (Turhan et al., 2008). International food regulations stipulate that honey is a pure product that does not allow for addition of any other substance (Diacu and Tantaveanu, 2007), including, but not limited to, water and other sweeteners. However, honey adulteration is a common phenomenon, especially in certain areas of the world. The adulteration leads to reduced nutritional value of honey, and thereafter, could cause health concerns to the consumers who rely on nutrients from honey products. Therefore, detection of honey adulteration is required to ensure quality and human safety. Currently, honey quality is measured by sensory and chemical analyses. The sensory analysis mainly detects honey color, viscosity, smell, flavor and crystallization. The accuracy of this method is limited and usually is influenced by sensory panelists and their experiences. The chemical analysis mainly includes chromatography, optical analysis, electroanalytical methods and mass spectrometry. Expensive instruments, complicated procedures and process time make chemical analysis impractical in the industry. Therefore, the development of a simple, rapid and low cost honey quality sensor is needed.

Dielectric properties or permittivities are intrinsic properties that determine the interaction of electromagnetic energy with materials. They are commonly represented by a complex number, the relative complex permittivity $\varepsilon^* = \varepsilon' - j\varepsilon''$, where the real part ε' (dielectric constant) is associated with the capability of energy storage in the material, and the imaginary part ε'' (loss factor) associated with energy dissipation in the material in the form of heat. Knowledge of the dielectric properties of various agri-foods and biological materials are finding increasing applications, and dielectric property measurement techniques have been adapted for use in various industries and research laboratories (Venkatesh and Raghavan, 2005). Extensive work has been done on a large number of agricultural products and foods, and shows that the electromagnetic wave frequency (García et al., 2004; Guo et al., 2007a,b,c; Ragni et al., 2007; Tanaka et al., 2005), and food compositions, especially moisture content (Kraszewski et al., 1999; Mabrook and Petty, 2003; Martín-Esparza et al., 2006; Tanaka et al., 2005; Trabelsi and Nelson, 2004), are the most important factors influencing materials' dielectric properties.

In honey adulterations, water is the most common ingredient. Water is also the most important ingredient affecting the dielectric properties of a material. It is very interesting to study how water influences the dielectric properties of honey, and to determine whether the dielectric properties could be used for determining water content or sugar content in honey and to detect water adulterations. So far, only limited information is available on dielectric

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properties of honeys. The dielectric properties of honey–water mixture were investigated using the time-domain reflectometry technique from 10 MHz to 10 GHz at 25 °C by Puranik et al. (1991). It was found that the addition of water to honey leads to a decrease in the relaxation time, and the relaxation time decreased with increasing water content. However, the correlations between the dielectric properties and sugar content and between the dielectric properties and water content in honeys were not studied. Ahmed et al. (2007) measured physical properties of several Indian pure honeys, but only dielectric properties in the frequency range of 900 to 2550 MHz were reported. However, they did not study the influence of water content on honey dielectric properties. The objectives of our present study are (1) to investigate the dielectric properties of honeys from 10 to 4500 MHz at 25 °C; (2) to study the effect of water on dielectric properties of honeys; (3) to determine the best frequency for establishing the relationship between dielectric properties and water and sugar contents; and (4) to estimate whether the relationship found can be used to predict honey sugar content and/or water content in practice.

2. Materials and methods

2.1. Honeys

Yellow locust flower honey, jujube flower honey and rape flower honey, packed in glass bottle by Shaanxi Dangdai Honey Industry Co. Ltd., were purchased from a local supermarket in Yangling, Shaanxi, China. The initial water contents of the samples used in the study were controlled at 18% by the corporation, and the samples were regarded as pure honeys. The main sugar compositions of the samples are listed in Table 1.

2.2. Dielectric properties measurements

The dielectric properties were measured with an Agilent Technologies 85070B open-ended coaxial-line probe and an Agilent Technologies E5071C vector network analyzer (Agilent Technologies, Malaysia). Dielectric constant and loss factor were calculated with Agilent Technologies 85070D dielectric probe kit software according to the reflection coefficient of the material in contact with the active tip of the probe. Settings were made to provide 101 measurements on a logarithmic scale from 10 to 4500 MHz. Before measurement, the E5071C Network Analyzer was calibrated with an open, short, and matched load in sequence at the port used for the measurement. Next, the cable for the 85070E open-ended coaxial-line probe was connected to the calibrated port. The computer program Agilent Connection Expert was initiated, which connects the network analyzer and the computer before initiating the 85070C computer program to perform the instrument setup. The dielectric probe was calibrated by using air, short-circuit, and 25 °C deionized water. A measurement was made on 25 °C deionized water to verify the performance of instruments after the calibration. When the probe was immersed in the deionized water during calibration and measurement, an effort was made to avoid air bubbles between water and the probe surface. During the experiment, any movement or change with the rigid cable used to connect the analyzer and the probe was avoided, since any subtle movement could affect measurement results.

Table 1
The main sugar compositions of three pure honeys used in the study.

Honey	Glucose (%)	Fructose (%)	Sucrose (%)	Total content (%)
Yellow locust	32.29	45.31	1.94	79.54
Jujube	33.90	40.50	1.66	76.06
Rape	40.34	37.66	1.75	79.75

2.3. Procedures

Known amount of deionized water was added to 70 ml pure honey, with 18% initial water content, of each kind to prepare the adulterated honey samples with different final water contents (22.1%, 26.2%, 30.3%, 34.4%, 38.5% and 42.6%, w/w) at room temperature. Masses of deionized water and honeys were determined with an FA2104A electronic balance (Shanghai Precision Scientific Instrument Co. Ltd., Shanghai, China) with precision of 0.0001 g. The samples were stirred with a glass stick slowly to mix the water and honey evenly. Total soluble solids content (or Brix) of honey samples were determined by a WYT refractometer (Chengdu Xingchenguang Optical Instrument Ltd., Chengdu, China) and were used as an indicator for sugar content. Three replicates were made on each sample. The mean and standard deviation values were used in the reported results.

Each beaker of 10 ml, filled with pure honey or water-adulterated honey solution up to a depth of 30 mm, was placed on a platform of 50 mm in diameter, and then was raised up until the downward open-ended coaxial-line probe was completely immersed in the sample. Honey is a very viscous fluid, and air bubbles are easily trapped. Any air bubble between the probe and samples interfaces with proper permittivity determination. For yellow locust, jujube and rape flower honeys used in this study, since they are transparent, air bubbles can be easily seen. Therefore, when no bubble was observed between the probe and sample, dielectric property measurements at 101 frequencies from 10 to 4500 MHz were performed in 1 min. Three replications for each sample were made. Between replications, the probe was washed with water and wiped dry. Our preliminary test results showed that the beaker size did not influence honey permittivities. All measurements were conducted at 25 ± 1 °C. After obtaining permittivities and total soluble solids content of each sample, the linear relationships between permittivities, i.e., dielectric constant and dielectric loss factor, and total soluble solids content, and between permittivities and water content were regressed at 101 discrete frequencies from 10 to 4500 MHz.

2.4. Penetration depth

Penetration depth, d_p, of radio frequency and microwave power is defined as the depth where the power is reduced to $1/e$ ($e = 2.7183$), about 37%, of its value at the surface of the material. The d_p value in meter in a lossy material can be calculated (Metaxas and Meredith, 1993) as follows:

$$d_p = \frac{c}{2\pi f\sqrt{2\varepsilon'\left(\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}-1\right)}} \tag{1}$$

where c is the speed of light in free space (3×10^8 m/s), f is the frequency in Hz, ε' and ε'' are obtained dielectric constant and loss factor of a material, respectively. Once the dielectric properties have been obtained, the penetration depth of electromagnetic energy in the selected materials can be calculated at the required frequency.

3. Results and discussion

3.1. The frequency dependence of dielectric properties of pure honeys

The measured dielectric properties of three kinds of pure honey over the frequency range from 10 to 4500 MHz at 25 °C are illustrated in Fig. 1. The results reveal that the permittivities of the