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Research Paper

Dielectric properties of peanut kernels associated with microwave and radio frequency drying

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To develop advanced drying methods based on microwave (MW) and radio frequency (RF) heating, knowledge of dielectric properties is essential for understanding the interaction between electromagnetic fields and peanuts. In this study, dielectric properties of peanut kernels were measured between 10 and 4500 MHz using an open-ended coaxial-line probe and network analyser at temperatures between 25 and 85 °C and moisture contents between 10% and 30% on a wet basis (w.b.). The results showed that both dielectric constant and loss factor of peanut kernels decreased sharply with increasing frequency over RF range (10–300 MHz), but gradually over the MW range (300–4500 MHz). Both dielectric constant and loss factor increased with increasing moisture content and temperature. The rate of increase was greater at higher temperature and moisture levels than at their lower levels. Penetration depth decreased with increasing frequency, moisture constant, and temperature. The measured dielectric properties were finally applied to determine the temperature profiles of RF heated samples under three moisture levels using experiment and simulation. This study on dielectric properties may provide useful guidelines in developing effective dielectric drying methods with a suitable drying thickness for peanuts.

1. Introduction

Peanuts (Arachis hypogea L.) are a widespread leguminous crop, mainly distributed in tropical and subtropical regions, including Africa, Asia and America. The world peanut production was about 45 Mt in 2013, and China is the country producing the most peanuts with about 17 Mt accounting for 37.8% of the total world production (FAOSTAT, 2013). Peanuts have a high nutritive value, and are a rich source of oils (44–56%), proteins (22–30%), minerals (phosphorus, calcium, magnesium and potassium), and vitamins (Asibuo et al., 2008). Adequate postharvest treatments may ensure the required good quality and storage stability of peanuts.

Drying is one of the most significant steps of post-harvest handling and storage of peanuts. The moisture content of peanut kernels at the time of harvesting is 30–50% on a wet basis (w.b.), and should be reduced to 10.5% or below for safe storage (Krzyzanowski, West, Neto, & de Barros, 2006). Usually, sun and hot air drying methods are commonly used for

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peanut drying (Yan, Nu, Hu, Xie, & Wang, 2012). The slow sun-drying rate is further influenced by the local solar intensity and ambient relative humidity (Bader, Adkins, & Butts, 1996) and sometimes results in poor product quality under rain (Yan, Nu, Zhi-Chao, Xie, & Wang, 2012). Hot air drying also takes a long time (e.g. 11 h at 40 °C) with low heating efficiency (Javare Gowda, Shivaprasad, & Ramaiah, 2012) and sometimes causes product quality degradation (Krzyzanowski et al., 2006). Therefore, it is of great significance to develop an advanced and efficient technology to replace the traditional drying methods.

Radio frequency (RF) and microwave (MW) treatments provide fast and volumetric heating due to internal heat generation throughout agricultural products via dipole rotation and ionic conductance. The dielectric heating results in short drying time and uniform drying rate in the products, and acceptable product quality, suggesting it may be able to replace the conventional drying methods. The RF and MW heating has been studied as potential advanced drying methods for several agricultural products, such as apricots (Albanese, Cinquanta, Cuccurullo, & Di Matteo, 2013), green peas (Zielinkska, Zapotoczny, Alves-Filho, Eikevik, Blaszczak, 2013), macadamia nuts (Wang et al., 2014), and wood (Leuca et al., 2014). Especially for RF drying, self-balancing effect of moisture level has been observed in various agricultural products due to less RF energy absorbed at locations with low moistures (Ling, Guo, Hou, Li, & Wang, 2015a; Wang, Zhang, Gao, Tang, & Wang, 2013). Therefore, having a good knowledge of dielectric properties of peanuts is essential to design an effective drying process for peanuts using RF or MW energy (Goyette, Chahine, Bose, Akyel, & Bosisio, 1990; Sosa-Morales, Valerio-Junco, López-Malo, & García, 2010).

Dielectric properties of materials determine how much electromagnetic energy can be stored and dissipated when they are exposed to RF or MW heating, and are commonly expressed as the complex permittivity, $\varepsilon = \varepsilon' - j\varepsilon''$. The real part, ε', is the dielectric constant, and represents a material's ability to store the electric field energy. The imaginary part, ε'', is the dielectric loss factor, and refers to the dissipation of electric field energy in the form of heat (Guo, Nelson, Trabelsi, & Kays, 2007).

Many studies on dielectric properties of food and agricultural product have been reported over different frequency, temperature and moisture ranges for drying (Wang et al., 2013), pest control (Ling, Tiwari, & Wang, 2015b; Wang et al., 2005), and pasteurization (Wang, Wig, Tang, & Hallberg, 2003; Zhu, Guo, & Wu, 2012a). Several studies on dielectric properties of nuts are available. Wang et al. (2003b) studied dielectric properties of almond and walnut kernels over the frequency range from 1 to 1800 MHz and temperature between 20 and 60 °C with moisture content 3% w.b. using the open-ended coaxial probe method. Ling et al. (2015a) developed quadratic polynomial equations for non-salted pistachio kernel samples to explain the relationship between moisture content, temperature and dielectric properties at four specific frequencies (27, 40, 915, and 2450 MHz). Zhu, Guo, Wu, and Wang (2012b) reported that the dielectric properties of chestnut flour decreased with increasing frequency and increased with increasing moisture content and temperature. Boldor, Sanders, and Simunovic (2004) studied dielectric properties of shelled and in-shell peanuts at several densities, moisture contents, and temperatures in the range of 300–3000 MHz. Dielectric properties of peanuts over different bulk density and moisture content at 23 °C between 2 and 18 GHz using a free-space-transmission technique were also reported by Trabelsi and Nelson (2004). However, there are few data for dielectric properties of peanuts over different temperatures and moisture contents at radio frequencies.

The objectives of this study were (1) to study frequency (10–4500 MHz), moisture content (10–30% w.b.) and temperature (25–85 °C) dependent dielectric properties of peanut kernels, (2) to provide the empirical equations describing peanut kernel's dielectric properties as function of moisture content and temperature at interested frequencies (27, 40, 915, and 2450 MHz), (3) to determine the penetration depth of electromagnetic energy into peanut kernels at four frequencies (27.12, 40.86, 915, and 2450 MHz) that refer to the industrial RF and MW applications, and (4) to confirm the RF heating rate of peanuts at three different moisture content (10%, 20%, and 30% w.b.) using experiment and simulation.

2. Materials and methods

2.1. Materials

The variety of shelled peanuts used in this study was "Huayu 20", which was purchased from a local farm market in Yangling, Shaanxi, China. The peanuts were stored in polyethylene bags at 4 °C until conducting tests. The chemical compositions of the peanuts determined with standard methods are summarised in Table 1 (AOAC., 2005).

2.2. Moisture content measurements

Moisture content of the peanuts was determined by the AOAC Official Method 925.40. Peanut samples were ground into powder. About 4–5 g peanut kernel flour was placed in an aluminium disk and dried to a constant weight at 95–100 °C under pressure ≤0.1 kPa in a vacuum oven. Then, the peanut kernel flour was cooled in a desiccator before weighing. The weight change was used to estimate the moisture content of the peanuts. Each measurement was conducted in triplicate and used to calculate the average moisture content.

2.3. Sample preparation and true density measurement

Based on the original moisture content (7.887% w.b.) of the peanut samples, 200 g peanuts in 5 prepared plastic bottles were sprayed with a predetermined amount of distilled water to obtain samples with 5 needed moisture content levels (10,

Table 1 – Chemical compositions of the peanuts.

Compositions	Content (g 100 g^{-1})	Methods
Moisture	7.89	AOAC 925.40
Fat	54.25	AOAC 948.22
Protein	24.54	AOAC 950.48
Total soluble solids	10.00	AOAC 950.50