Dielectric Spectroscopy Technique for Carbohydrate Characterization of Fragrant Rice, Brown Rice and White Rice

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Abstract— This study was conducted to investigate the feasibility of microwave dielectric spectroscopic technique in characterizing commercial rice due to different level of moisture content. There are some unethical rice industry runner mixes good qualities of rice which can be sold at high price with low cost and quality of rice to maximize profit. It causes fraudulency in business and great lost in term of money to nation who take rice as staple food. It happens frequently in Asian country which is active in agricultural activities. This technique is implemented using Keysight E8362B network analyzer in conjunction with an Keysight 85070E dielectric probe ranging from 200 MHz to 10 GHz. The samples of study are commercially available at market, namely fragrant rice, white rice, and brown rice, respectively. These are the popular and favorite rice for Malaysian due its delicacy and affordable price. Nutrient level for fragrant rice, white rice, and brown rice in terms of protein, moisture, carbohydrate and fat are different and unique. It leads to various electromagnetic responses toward frequency. Dielectric and reflection measurement were conducted to characterize these rice. The presence of polar and non-polar molecules in nutrient of rice causes variation of dielectric and reflection behavior over the operating frequency range.

1. INTRODUCTION

Rice is staple food for most of the Asia countries, such as China, Korea, Japan, Indonesia, Malaysia and etc.. It can be found in different brand and type in market. Consumer can find their favorite type of rice. Fragrant rice, white rice, and brown rice are popular among Malaysian due to its price, nutrient and taste. In many literatures, the quality indicator of rice is moisture content, shape, chalkiness, whiteness and number of broken rice [1, 2]. In fact, the nutrient presented in rice should be one of the indicators too. A research was conducted for nutrient analysis in rice: water, protein, fat and Carbohydrate [3]. Rice provides abundant carbohydrates which is the major source of energy for Malaysian where carbohydrate can be broken down to glucose in simple form. In order to produce edible rice from paddy, process of milling and polishing are necessary. However, it causes lost in nutrients when the outer rice husk and bran of rice is removed [4]. Content of moisture, fat, carbohydrate and protein of the three types of rice are tabulated in Table 1.

Dielectric spectroscopy technique was extensively used to investigate nutrient of food. Literature [5] reported about dielectric study on protein concentration in aqueous solutions of ribonuclease A at 298.15 K in the MHz/GHz frequency range [5]. Amino acid (simple form of protein) is presented in different character due its molecular weight and side-chain group [6]. Fatty acid is also presented in polar and nonpolar molecule where it contributes significant effect to dielectric behavior. It has close-knit relationship between the structure and the dielectric properties of fatty

Table 1: Nutrition information in rice for amounts per 1 cup (158 g).

Rice	Fat (g)	Carbohydrate (g)	Protein (g)
Fragrant	0.6	122.5	11.3
Brown	1.5	36.3	4.1
White	0.4	44.5	4.2

acids. Likewise, the status of polarity for 8 fatty acids in fat can be distinguished through molecular weight and polar moment which is presented within molecules. Meanwhile, carbohydrate can be broke down into glucose.

Dielectric properties are measured in complex permittivity, ε_r which is consist of dielectric constant, ε_r' (real part) and loss factor, ε_r'' (imaginary part). The ε_r' and ε_r'' depict behavior of a material/molecule in storing and dissipating electrical energy, respectively it subjected to time-varying electromagnetic field. The polarization occurs upon response of a material/molecule due to variation of polarity of applied field. When these polar and ionic substances are subjected to frequency dependent applied field, orientation polarization is taken place. The polar molecules tend to align themselves according to direction of applied field [7]. Relaxation frequency of each polar molecule that presented in rice is crucial in determining the status of polarization. Content of protein and fat contribute insignificant amount in rice. Carbohydrate and moisture are the major component in white rice, brown rice and fragrant rice. Carbohydrate is essentially glucose. Glucose is monosaccharide which belongs to carbohydrate class. The molecular formula for glucose is $C_6H_{12}O_6$. Glucose and fructose are differ in their structural formula where glucose consists of a ring with six atoms while fructose consists of a ring with five atoms. The molecular weight for glucose and fructose is 180 grams/mol. The dipole moment for fructose and glucose are 3.65 Debye and 1.8 Debye, respectively [8].

On the other hand, moisture/water content (H_2O) is a chemical compound. It consists of two hydrogen atoms bond with one oxygen atom. Water is classified as polar molecule due to its asymmetrical molecule structure. It provides dipole moment due to uneven distribution of charge in molecule of H_2O. Water has a dipole moment of 2.4 Debye in liquid state [9] and 18 grams/mol of molecular weight. Apart from it, water is able to make strong electrostatic interactions with itself as well as other molecules and ions. For instance, when the rice grain is exposed to the microwave, the water molecules in the rice grain will be induced to rotate as shown in Figure 1 [10, 11].

The main objective of this study is focused on the change of carbohydrate content in the rice to its dielectric properties. Thus, the rice samples used are in the powder form, so-called ground rice. Subsequently, the air gap errors in the measurement can be avoided. In addition, moisture content in the three samples will be almost the same due to most moisture content is lost to the atmosphere, hence the moisture factor will not affect the change of dielectric measurement.

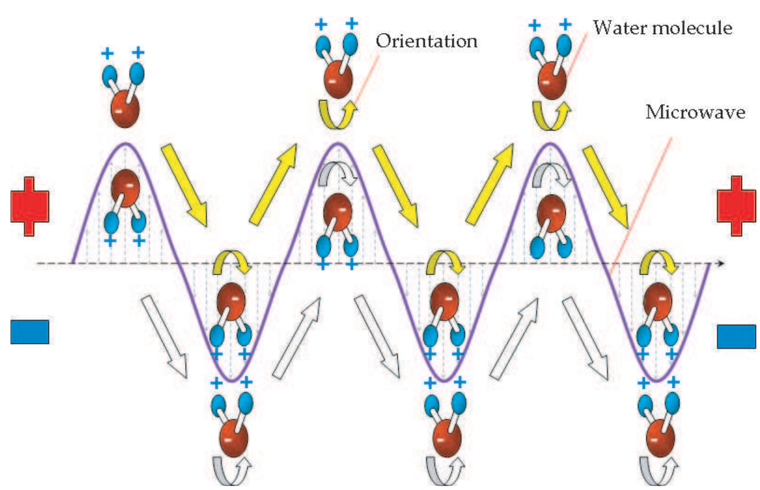


Figure 1: Water molecules are oriented when exposed to microwave [10].

2. METHODOLOGY

In this work, fragrant rice, white rice, and brown rice are taken as samples under test and they are commercially available. Beakers were prepared to fill with sample. On the other hand, fragrant rice, white rice, and brown rice were ground to prepare similar samples in powder form. It could ensure air void within samples can be mitigated. The relative complex permittivity ($\varepsilon_r = \varepsilon_r' j\varepsilon_r''$) of rice samples is measured by using Keysight 85070E dielectric probe ranging from 200 MHz to 10 GHz at room temperature as shown in Figure 2(a). Probe calibration is performed before dielectric measurement has been done. The probe calibration consists of air, short-circuits and deionized water. The reflection measurement is conducted using Keysight E8362B Network Analyzer (PNA) in conjunction with the dielectric probe too ranging from 200 MHz to 10 GHz at room temperature. The PNA calibration needs to be conducted prior to measurement for removal of systematic errors using open, short and broadband load kits as shown in Figure 2(b). The sample is made to in contact with the aperture of the dielectric probe. Then, the complex reflection coefficient of the rice samples in terms of magnitude, $|\Gamma|$ and phase, ϕ are measured.

(a) (b)

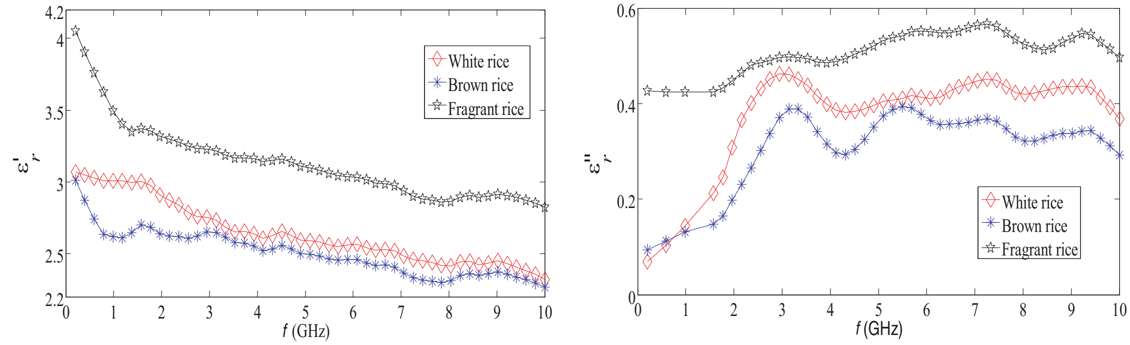
Figure 2: (a) Keysight 85070E probe. (b) Keysight 85052D mechanical calibration kit.

3. RESULTS AND DISCUSSION

Ground rice mitigates the effect due to presence of air void. The air void can be easily filled by small particle of ground rice. In Figure 3, it can be noticed that dielectric constant, ε_r' is generally decreases when frequency increases for all type of rice. This might be due to the presence of polar molecules, such as glucose and fructose molecules (simple forms of carbohydrate) in sample. When frequency increases, these polar molecules are not able to reorient synchronously with the operating frequencies. Dipolar polarization in polar molecules cannot be conducted when frequency increases. Hence, ε_r' decline as frequency increases. Ground fragrant rice exhibit the highest ε_r' over frequency when comparing with ground brown rice and white rice. It is attributed to the highest percentage of carbohydrate in fragrant rice, such as 77.2% (122 g/158 g). The simple form in carbohydrate is majority consist of glucose and fructose for fragrant rice. In Table 1, it can be noticed that amount of carbohydrate is even higher than moisture in brown rice and white rice. Although moisture (H_2O) has higher dipole moment than glucose, significant amount of glucose and fructose where they have dipole moment of 1.8 Debye and 3.65 Debye, respectively still lead to highest ε_r'. It might primarily due to highest dipole moment of fructose when compared with H_2O. High dipole moment implies that large magnitude of charge at electronegative and electropositive end of a polar molecule is split far apart due to long molecule structure like fructose. Subsequently, it enhances dielectric constant because electric susceptibility of fragrant rice was increased.

On the other hand, ground white rice has higher ε_r' than ground brown rice over frequency due to greater amount of carbohydrate content than in white rice as listed in Table 1. The significant variation of dielectric properties in ground white rice and ground brown rice is most probable due to presence of carbohydrate content, since the moisture content for both rice are approximately same. Furthermore, the most of the moisture content in rice grains has been lost to the atmosphere when through the destruction process in order to become ground rice. Substantial amount of water content in ground brown rice and white rice result to decrease the binding forces in relative ionic movement which increasing dipole rotation of free water [12, 13]. Dielectric polarization is inhibited attribute to less free water molecule. As a result, carbohydrate in ground white rice and brown rice has remarkable amount which is factor lead to distinction of their dielectric properties. Fructose play a vital role in exhibiting higher ε_r' for ground white rice than ground brown rice. It can be noticed through its high dipole moment.

When operating frequency increases, the dispersion of relaxation frequencies among molecules increase inharmonious during polarization. Polar and non-polar molecules are not able to rotate



(a) (b)

Figure 3: The variation of (a) ε_r' and (b) ε_r'' over frequency for white, brown, and fragrant rice.

synchronously with operating frequency, especially at high frequency. As a result, it can be found that ε_r'' decreases when frequency increases. It is applicable for all ground and unground rice. However, ε_r'' of all unground rice decrease with lower sensitivity than ground rice due to presence of air void. Relaxation frequencies among polar molecule and non-polar molecules are dissimilar in term of inertia. Hence, relaxation frequencies among these molecules disperse. The dispersion of inertia increases the asynchronous of rotation. Therefore, the loss due to friction among molecules significantly increases. At low ε_r', the dispersion of relaxation frequencies is low. Hence, low dispersion lead to mild friction among molecules. Less energy loss due to friction results in low ε_r''. As a result, lower ε_r' of ground brown rice has lower ε_r'' compared with ground fragrant rice and ground white rice and vice versa.

In Table 2, it can be observed that, in average, the measured linear magnitude of reflection coefficient, $|\Gamma|$ and reflection phase shift, ϕ for all samples under test decrease when frequency increases. It is consistent with frequency response of ε_r'.

Table 2: Collaboration between $|\Gamma|$, ϕ, ε_r', and ε_r''.

f	White rice				Brown rice				Fragrant rice			
(GHz)	$\|\Gamma\|$	ϕ (°)	ε_r'	ε_r''	$\|\Gamma\|$	ϕ (°)	ε_r'	ε_r''	$\|\Gamma\|$	ϕ (°)	ε_r'	ε_r''
2.46	0.9346	−298.0	2.814	0.417	0.9352	−296.5	2.612	0.284	0.9333	−297.5	3.262	0.484
5.8	0.9197	−708.7	2.561	0.415	0.9217	−705.5	2.459	0.378	0.9166	−707.3	3.038	0.553
10	0.9079	−1212.8	2.322	0.369	0.9161	−1208.7	2.270	0.293	0.9007	−1210.3	2.825	0.498

4. CONCLUSIONS

A microwave reflection measurement system which consists of Keysight E8362B Network Analyzer in conjunction with an Keysight 85070E High Temperature Probe is used for the sake of reflection and dielectric measurement of ground white rice, brown rice and fragrant rice. The complex reflection coefficient in terms of magnitude, $|\Gamma|$ and phase, ϕ were measured using the same probe. The measured ε_r' of all samples under test decrease over frequency. Meanwhile, ε_r'' increases for all sample under test over frequency. The similar trend line can be observed through $|\Gamma|$ and ϕ. The dielectric mechanism was conducted when in polar molecules of nutrient, such as moisture content and carbohydrate (glucose) in sample interacted with a time-varying field. The effect of moisture content and carbohydrate on the dielectric properties is major factor lead to the variation of ε_r' and ε_r''. In summary, the dielectric measurement present good agreement in characterizing white rice, brown rice and fragrant rice.

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REFERENCES

1. Singh, D. K., P. Kumar, and N. Z. Rizvi, "Microstrip transmission line sensor for rice quality detection: An overview," *International Journal of Engineering Research and General Science*, Vol. 2, 589–598, June–July 2014.
2. Mun, H. K., K. Y. You, and M. N. Dimon, "Broken rice detection based on microwave measurement technique using microstrip wide-ring sensor and microstrip coupled-line sensor," *Australian Journal of Crop Science*, Vol. 7, 2079–2090, 2013.
3. Mohd Fairulnizal, M. N., M. K. Norhayati, A. Zaiton, A. H. Norliza, S. Rusidah, A. R. Aswir, M. Suraiami, M. N. Mohd Naeem, A. Jo-Lyn, J. Mohd Azerulazree, B. Vimala, and T. Mohd Zainuldin, "Nutrient content in selected commercial rice in Malaysia: An update of Malaysian food composition database," *International Food Research Journal*, Vol. 22, 768–776, 2015.
4. Kennedy, G. and B. Burlingame, "Analysis of food composition data on rice from a plant genetic resources perspective," *Food Chemistry*, Vol. 80, 589–596, 2003.
5. Oleinikova, A., P. Sasisanker, and H. Weingärtner, "What can really be learned from dielectric spectroscopy of protein solutions? A case study of ribonuclease A," *The Journal of Physical Chemistry B*, Vol. 108, 8467–8474, May 2014.
6. Pethig, R., "Dielectric properties of biological materials: Biophysical and medical applications," *IEEE Transactions on Electrical Insulation*, Vol. 19, 453–474, October 1984.
7. Cheng, E. M., M. F. A. Malek, S. F. Khor, K. Y. You, K. Y. Lee, Mohd Afendi R., A. B. Shahriman, M. N. Nashrul Fazli, Z. Zulkarnay, and W. H. Tan, "Reflection and dielectric measurement for salinity of water using microstrip loop antenna and dielectric probe," *International Journal of GEOMATE*, Vol. 11, 2335–2340, 2016.
8. Mazurkiewicz, J. and P. Tomasik, "Effect of external electric field upon charge distribution, energy and dipole moment of selected monosaccharide molecules," *Natural Science*, Vol. 4, 276–285, 2012.
9. Sharp, K. A., *Water: Structure and Properties*, 1–7, Encyclopedia of Life Sciences, John Wiley and Sons, New York, 2001.
10. You, K. Y., L. L. You, C. S. Yue, H. K. Mun, and C. Y. Lee, "Chapter 6 physical and chemical characterization of rice using laboratory and microwave methods," *Rice-Technology and Production*, Amanullah and S. Fahad, ed., 81–99, InTech, US, 2017.
11. You, K. Y., H. K. Mun, L. L. You, S. Jamaliah, and A. Zulkifly, "Small and slim coaxial probe for single rice grain moisture sensing," *Sensors*, Vol. 13, No. 3, 3652–3663, 2013.
12. Calay, R. K., M. Newborough, D. Probert, and P. S. Calay, "Predictive equations for the dielectric properties of foods," *International Journal of Food Science and Technology*, Vol. 29, 699–713, 1995.
13. Komarov, V., S. Wang, and J. Tang, "Permittivity and measurements," *Encyclopedia of RF and Microwave Engineering*, K. Chang, ed., 3693–3711, John Wiley and Sons, New York, 2005.