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RESEARCH ARTICLE

Frequency dependence of the dielectric properties of two cultivars of watermelon at microwave frequencies and their nutrients

[1]Ravika Vijay*, [2]Komal Jangid, [1]Ritu Jain, [1]K.S. Sharma
[1]Department of Physics
[2]Department of Home Science
The IIS University, Gurukul Marg, SFS, Mansarovar, Jaipur-302020 INDIA

Abstract

The dielectric constant and loss factor of fresh watermelon, 1. Sugar Baby-with dark green peel; and 2. Arka Manik – with light green and white stripes on its peel, were measured at room temperature (28°C) and at four microwave frequencies in C, J, X and Ku bands. One of the two samples of each cultivar was taken to contain red colored internal tissues of fully matured watermelon, whereas the second sample of each cultivar was taken to contain a mix of matured red colored tissues, and raw white colored internal tissues along with peel. It has been observed that the Dielectric constant of all the four samples, decreases with increase in frequency, whereas the loss factor is observed to remain nearly uniform for the samples containing only red tissues, while for the other samples of the two cultivars, the loss factor decreases first rapidly and then slowly with increase in frequency. The nutrient values of the four samples of water melon, as determined by using standard laboratory techniques, are reported and their correlation with the dielectric properties is established graphically.

Keywords

Dielectric constant, Dielectric loss factor, Fruits, Moisture, Nutrients ,Watermelon

Introduction

Dielectric properties directly influence microwaves drying characteristics of food products. A knowledge of dielectric properties of different varieties of food in therefore essential in the design and control of microwave drying systems and in determining their efficiency (Feng *et al*, 2002).

The knowledge of dielectric properties has been used for sensing moisture content in agricultural products and food grains so as to determine their safe storage (Nelson, 1977). Radio frequency and microwave dielectric heating has also been used for various applications like pest control in the crops and fruits (Nelson, 1996 and Ikediala *et a*l, 2000), for seed treatment (Nelson and Stetson, 1985), for product conditioning (Pour-El *et al*, 1981; Senter *et al*, 1984), for remote sensing of crop condition (Ulaby and Jedlicka, 1982), for determination of maturity of fruits and for quality measurement of fruits and corps (Nelson, 1980; Nelson *et al*, 1995).

Interaction between a food product and microwave energy is governed by the relative complex permittivity ($\varepsilon_r = \varepsilon' - J\varepsilon''$) of the product. The real component of the complex permittivity (ε″, known as the dielectric constant) in related to energy storage, and the imaginary component (ε″, the loss factor) is related to the energy dissipation in the dielectric medium.

In connection with quality sensing of fruits and vegetables, the dielectric properties of twenty three kinds of common fresh fruits and vegetables were investigated by Nelson, 1983 over the frequency range from 200 MHz to 20 GHz at 23°C, by employing a network analyzer and coaxial probe.

Dielectric properties of four small-sized watermelon cultivars, grown and harvested to provide a range of maturities, were measured by Nelson *et al*, 2007, with an open-ended coaxial-line probe and impedance analyzer over the frequency range from 10 MHz to 1.8 GHz. Probe measurements were made on the external surface of the melons and also on tissue samples from the edible internal tissue. Moisture content and soluble solids content (SSC) were measured for internal tissue samples, and SSC (sweetness) was used as the quality factor for correlation with the dielectric properties. Individual dielectric constant and loss factor correlations with SSC were low, but a high correlation was obtained between the SSC and permittivity from a complex-plane plot of dielectric constant and loss factor, each divided by SSC. The sugar content is the most significant factor affecting the maturity

*Corresponding Author : Email : ravikavijay@gmail.com

of watermelon. Sugar content in 10 matured red seedless watermelons was measured by Ibrahim *et al*, 2009 to comparison of watermelon juice with sugar solution in water, over the frequency range 200 MHz to 20 GHz and using an open ended coaxial – line probe and network analyzer. In this study data obtained suggests that dielectric properties show strong relationship with sugar content.

Several cultivars of cantaloupe, honeydew melons, and watermelons were planted and harvested by Nelson *et al*, 2008, with a range of maturities for dielectric properties measurements, moisture and soluble solids content (SSC) determination. Dielectric constants and dielectric loss factors were determined over the frequency range from 200 MHz to 20 GHz with an open ended coaxial line probe and network analyzer for both interior tissue and surface measurements. Dielectric properties determined by measurements on the external surface of the melons had lower values than those of the internal tissues. Dielectric properties were similar for all three melon types, and they reflect the influence of the dielectric behavior of free water.

However, no results have been reported in literature on the dielectric prpperties of indian species of watermelon. As such, it was decided to investigateresentation of the same for longer period. Two point method was used for determination of dielectric properties of the two cultivars of watermelon, as it has been found to predict successfully the dielectric properties of medium and low loss dielectrics. In order to see dielectric behavior at different frequencies, four microwave benches (C, J, X and Ku bands) are used. For determination of nutrients we used standard AOAC techniques (Bhargava *et al*, 2013).

Materials and Method

Preparation of Samples for Determination of Dielectric Properties

Fresh samples of two cultivars of watermelon as needed for the present research were obtained from the local market. The two cultivars selected for the present study include:

(A) Sugar Baby (SB) and (B) Arka Manik (AM)

Two samples of each cultivars were taken and represented by symbols as given below:

SB-S1 (red coloured internal tissues of fully mature watermelon Sugar Baby with seeds)

SB-S2 (a mix of red and white colored internal tissues along with peel of dark green color of Sugar Baby)

AM-S1 (red coloured internal tissues of fully mature watermelon Arka Manik with seeds)

AM-S2 (a mix of red and white colored internal tissues of Arka Manik along with peel, having light green and white stripes on it)

From the samples selected as above, experimental samples were prepared by cutting samples of different cross-sectional area as per internal dimensions of waveguide of different microwave frequency bands. For each microwave band, samples of two different lengths were taken as per requirement of two point method employed in this work. The dielectric parameters, viz., ε' and ε'' of the four samples were measured by two point method at microwave frequencies by employing C, J, X and Ku band microwave benches.

Two point method

Two point method is a technique involving measurement of reflection coefficient of a solid placed in a wave guide, backed by a short circuiting conducting plate. The experimental set-up for this method is shown below in Fig. 1. In order to use this method for fruits and vegetables; a specially designed dielectric cell is used to hold the samples. The samples are cut in to pieces with cross-sectional area equal to that of the waveguide and length in the range $\lambda/4 < \lambda/2 < 3\lambda/4$. The samples so obtained are inserted inside the dielectric cell which is shorted with the help of a metal plate, such that the sample is in contact of the metal plate. This method is suitable for low and medium loss dielectrics and can be adopted for measurement of dielectric properties in solid form Susher and Fox, 1963.

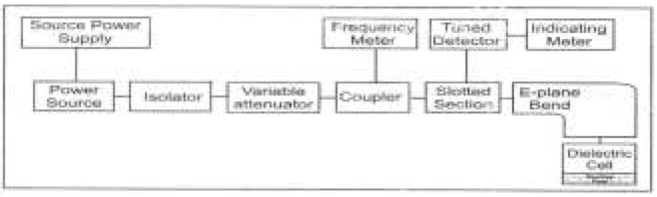

Fig.1. Experimental set-up for determination of dielectric properties by two point method

In two point method, the complex dielectric constant is given by

$$C\angle -\psi = \frac{1}{j\beta l_{\epsilon}} \frac{1-|r|\, e^{j\psi}}{1+|r|\, e^{j\psi}} = \frac{\tan X\angle\theta}{X\angle\theta} \quad (1)$$

The transcendental equation provides several solutions for $X / \_\theta$, which can be found by employing graphs and tables provided for solution of such equations by Hippel or alternatively the problem may be solved by mathematical tool like MATLAB. The experiment is repeated with a different length of the sample and the common root is chosen for evaluation of the admittance. Alternatively we may perform the experiment for a given sample at two different frequencies to obtain the correct root $X / \_\theta$.

The admittance Y_ε of the material of the sample is given by

$$Y_{\in} = \left(\frac{X}{\beta l_{\in}}\right)^2 \angle 2\left(\theta - 90^0\right) = G_{\in} + jS_{\in} \qquad (2)$$

Where G_ε and S_ε are respectively the conductance and susceptance of the sample.

The values of G_ε and S_ε are obtained by separating eq^n (2) into real and imaginary parts, from which the values of $\varepsilon^/$ and $\varepsilon^{//}$ can be obtained in the following form:

$$\in^{/} = \frac{G_{\in} + \left(\lambda_g / 2a\right)^2}{1 + \left(\lambda_g / 2a\right)^2} \qquad (3)$$

$$\in^{//} = \frac{-S_{\in}}{1 + \left(\lambda_g / 2a\right)^2} \qquad (4)$$

A computer program in MATLAB may be used to solve the transcendental equation and obtain the values of dielectric constant (ε″) and loss factor (ε″).

Preparation of Samples for Nutritive Value determination

Four samples of two cultivars of fresh watermelon were taken. The samples were graded and then put in the microwave oven in the microwave dish. The temperature inside the oven was kept constant at 100°C and the time interval was varied for dehydration of samples. After heating for about 40 minutes in the microwave oven, the samples are put for three hours in the dry hot air oven for evaporation of any remaining water content. Then the weight of dried samples is taken by using an electronic digital balance. The samples are again put in dry hot air oven for about half an hour and its weight is again taken. This process is repeated till the moisture gets completely removed.

The moisture free samples are put in zip lock plastic bags and kept in a freezer maintained at about 5°C. The samples are then analyzed for their nutritional composition, by estimating, moisture, crude protein, total ash, crude fiber, fate and carbohydrate, using standard laboratory methods AOAC, 2005. Three sets of observations are taken in each case for obtaining concurrence and estimation of experimental deviations.

Results and Discussion

The variation of dielectric constant (ε′) of watermelon with frequency for four samples SB-S1, SB-S2, AM-S1 and AM-S2, as obtained at 28°C is shown in Fig.2, from where it can be observed that ε″ decreases first rapidly and then slowly with increase in frequency for all the four samples. The variation of loss factor ε″with frequency in shown in Fig.3. It may be observed that whereas the loss factor for samples SB-S1 and AM-S1 (containing fully matured red

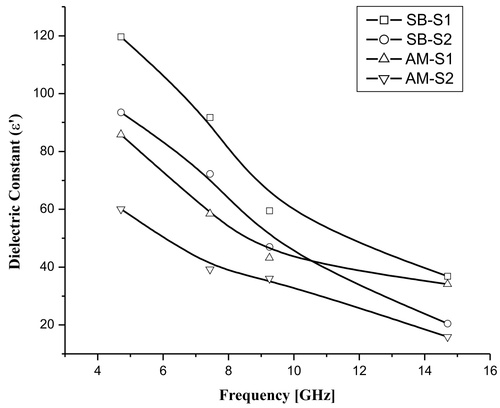

Fig. 2. Variation of dielectric constant of four samples (SB-S1, SB-S2, AM-S1 and AM-S2) of watermelon with microwave frequencies

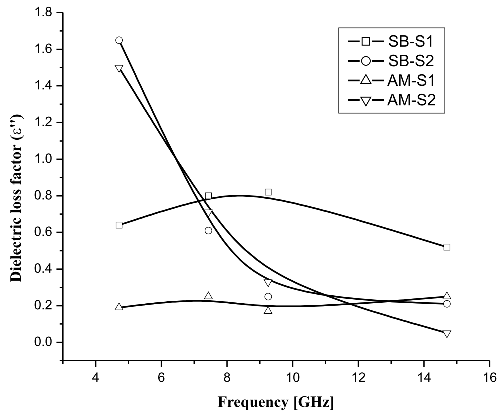

Fig. 3. Variation of dielectric loss factor of four samples (SB-S1, SB-S2, AM-S1 and AM-S2) of watermelon with microwave frequencies

tissues from the interior of watermelon) is nearly uniform, whereas for samples SB-S2 and AM-S2 (containing mix of red and white raw tissues along with peel), it is observed to decrease first rapidly and then slowly with frequency. The slope of ε″curves for these samples and ε′ curves for all the four samples are found to change curvature at about 9 GHz. ε″curves for samples SB-S1 and AM-S1 also show maxima and minima respectively at this frequency, though the maxima / minima are not prominent. Higher values of dielectric constant for samples SB-S1 and AM-S1 i.e., for interior red tissues of both the cultivars, suggest that interior of watermelon has higher capacity to store electromagnetic energy.

The lower values of ε′ for samples with peel suggest that their cellular structure is quite different from that of interior, so that peel and white raw tissues can store less electromagnetic energy. The absorption of electromagnetic waves and hence the losses in the samples SB-S2 and AM-S2 are found to be higher at lower range of microwave frequencies, which is close to the frequency at which microwave ovens work. As frequency increases the absorption and energy losses decrease, which is in the accordance with the general behavior of molecules at higher frequencies. For SB-S2 and AM-S2 (samples with peel) ε″ values fall almost linearly with frequency up to 9 GHz, and thereafter their slopes are changed, so that the curve for SB-S2 becomes almost flat. On the other hand for samples SB-S1 and AM-S1 (without peel) ε″ shows feeble dependence on frequency and we obtain a shallow hill for SB -S1, whereas a shallow dip at about 9 GHz along with a shallow hill at about 7.5 GHz are obtained for AM-S1.

The nutrients of the four samples as determined by the standard laboratory methods are displayed in Table 1. It may be observed from the table that whereas the quantity of moisture, crude protein and ash are nearly equal in the four samples, the Fat and Crude Fiber have higher values for SB-S2 and AM-S2 as compared to SB-S1 and AM-S1 and the carbohydrates have higher values for SB-S1 and AM-S1 as compared to SB-S2 and AM-S2. The correlation of nutritive values of four samples SB-S1, SB-S2, AM-S1and AM-S2 with their dielectric constant at frequency 9.25 GHz is shown in Fig. 4. It is observed from Fig. 4. that carbohydrate increases first and then decreases and again increases with increasing dielectric constant and fat just show reverse trend with increasing dielectric constant. Crude fiber also shows same trend as shown by carbohydrates but variation with increasing dielectric constant is smaller in this case. The straight line graphs obtained for moisture, total ash and crude protein show that these quantities have almost the same values for all the four samples and do not show any variation with dielectric constant. The variation of nutritive values with dielectric loss factor at frequency 9.25 GHz for the four samples SB-S1, SB-S2, AM-S1and AM-S2 is shown in Fig. 5. No definite trend for dependence of nutritive values on dielectric loss factor of the four samples is ,however, observed from Fig. 5.

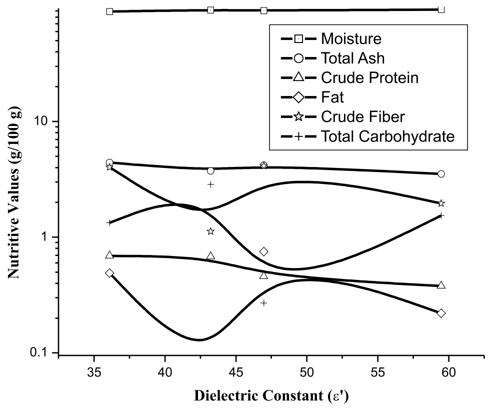

Fig. 4. Variation of nutritive values of four samples (SB-S1, SB-S2, AM-S1 and AM-S2) with dielectric constant at 9.25 GHz.

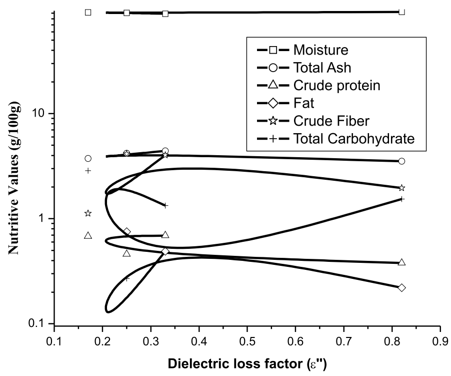

Fig. 5. Variation of nutritive values of four samples (SB-S1, SB-S2, AM-S1 and AM-S2) with dielectric loss factor at 9.25 GHz.

Table 1. Nutritive value estimation of four samples of watermelon (± Standard Deviation)

Nutrients / Samples	Moisture g/100g	Total Ash g/100g	Crude protein g/100g	Fat g/100g	Crude Fiber g/100g	Total Carbohydrate g/100g
SB-S1	92.37 ±0.45	3.53 ±0.27	0.38 ±0.14	0.22 ±0.03	1.96 ±0.03	1.54 ±0.77
SB-S2	90.73 ±0.32	4.19 ±0.31	0.46 ±0.05	0.75 ±0.07	4.14 ±0.04	0.27 ±0.81
AM-S1	91.74 ±0.36	3.75 ±0.20	0.68 ±0.14	0.06 ±0.02	1.12 ±0.19	2.87 ±0.40
AM-S2	89.05 ±0.42	4.42 ±0.25	0.69 ±0.07	0.49 ±0.03	4.02 ±0.07	1.33 ±0.75

Mean± Standard deviation

Conclusion

The two point microwave method for estimation of dielectric properties of materials can be successfully extended for dielectric studies of food materials such as fruits and vegetables. It is found that the ε′ values for the samples with peels are lower than the values for samples without peel. Whereas ε′decreases with increasing of frequency, no such trends are observed for ε″. ε′ is also observed to show dependence on nutrients like, carbohydrates, fats and crude fibre, no such dependence is however observed for ε″.

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