RESEARCH ARTICLE

Effect of Temperature and Grain Size Variations on Dielectric Properties of Buckwheat at 9.76 GHz

Swechchha Gupta*, Ritu Jain, Nidhi Bhargava

Department of Physics, IIS (deemed to be University), Jaipur.

Abstract

Dielectric properties of Buckwheat in powder form were determined and effect of grain size variation was studied at room temperature (22˚C) at a microwave frequency 9.76 GHz, by using Two point method. The results show that dielectric constant (ε') and dielectric loss (ε'') vary appreciable with grain size. The method proposed by Yadav and Gandhi (1992) was used to study the dielectric properties of Buckwheat in powder form using a specially designed dielectric cell and a constant temperature water bath. Effect of temperature variation was also studied in the temperature range 30˚C to 80˚C for Buckwheat (grain size 250-300 microns) at frequency 9.76GHz. It was observed that both the dielectric constant (ε') and dielectric loss (ε'') vary with temperature.

Keywords: Buckwheat, Dielectric constant, Dielectric loss, Microwave.

Introduction

Dielectric Properties

The dielectric properties are important for dielectric heating application of the microwave and radio frequency radiation. Dielectric properties of food products depend on their moisture content and hence determine the absorption and dissipation of electromagnetic energy when they are subjected to dielectric heating. The dielectric constant and dielectric loss factor provide the information about interaction of materials with electromagnetic energy. During heating by microwaves several variables in food impact the heating performance. One of the variables is permittivity which defines how a material will interact with electromagnetic radiation (Bhargava *et al.*, 2013a; Sharma *et al.*, 2010; Bhargava *et al.*, 2013b)

Dielectric permittivity of food grains depends on factors like frequency, temperature, moisture and biochemical composition, viz., carbohydrates, proteins, fats, vitamins and minerals (Bhargava *et al.*, 2013a).

Frequency and temperature dependence of dielectric properties of fresh potato juice at microwave frequencies were investigated by Vijay *et al.* (2013). Temperature dependence of the dielectric properties of Barley, Chickpea and Mustard seeds at frequencies 4.65 GHz, 7.01 GHz and 9.42 GHz and in the temperature range 30°C to 80°C were studied by Bhargava et al (2016). Both dielectric constant (ε') and the loss factor (ε'') were found to increase with increase in temperature by them. Measurements of the dielectric properties of whole grain wheat were made by Shrestha and Baik (2015) for the temperature range 15°C to 75°C. They found that the dielectric constant (ε') of the wheat increased almost linearly with temperature and the loss factor (ε'') increased non-linearly with temperature.

Gluten free grains

A gluten-free diet is a diet that strictly excludes gluten. There are many nutrients at micro & macro level which are available in gluten-free diet. These should have a good balance in gluten free diet to make it a nutritious and healthy diet. These may include: nuts, fruits, vegetables, potatoes, milk, dairy products, legumes, rice and corn. There are some other cereals also which have good biological & nutritional value, like finger millet, amaranth, buckwheat and other minor cereals. All of them contain a higher content of nutritional quality proteins as compared to those of wheat (Alifaki *et al.*, 2019).

Higher gluten content in diet can cause Celiac disease. Six to eight million Indians suffer from it. It is estimated

*Corresponding Author Email : swechchhagupta95@gmail.com

that every 1 out of 100 people suffers from celiac disease (Alifaki *et al.,* 2019). So for treating the patients who are suffering from this disease, gluten free diet is given. Because of increasing number of patients of celiac disease, demand for gluten-free products is increasing. The other reason for increase in this demand is increase in non-celiac gluten sensitivity and gluten allergy. So after researching on the same, the focus of the dieticians is on the application of those grains which are potentially healthy to prepare gluten-free products.

From the literature survey it is found that there is not enough literature available on the dielectric properties of gluten free food grains at microwave frequencies. The purpose of this paper is to study the grain size and temperature dependence of the dielectric properties of gluten free grain buckwheat.

Buckwheat

As its name suggests, it is neither related to wheat nor it is a grass. It is a plant which is cultivated for its grain-like seed and as a cover crop. Its name Buckwheatis also used for a number of other species. Buckwheat is mostly used on the days of Navaratri Festival in India. It is famous with name "Kuttu" in India. Buckwheat is mainly composed of carbohydrates. It also contains a good amount of fiber and resistant starch, which may improve colon health. Buckwheat is richer in minerals as compared to other pseudocereals and cereals. It contains good percentage of elements like, manganese, copper and magnesium. Buckwheat is helpful in maintaining moderate blood sugar levels and can also boost heart health by improving blood pressure (Wronkowska *et al.,* 2010; Alifaki *et al.,* 2019).

Materials and Method

Out of several gluten free grains available in the market, Buckwheat is used for the present study. Due to the irregular shape of whole grain, it become difficult to measure its dielectric properties. In order to reduce the measurement errors the sample was converted into the powder form (Nelson, 1992). The grains were grinded and samples having different grain sizes were obtained by using sieves of different mesh sizes. Thus the samples of grain sizes 90-150 microns, 250-300 microns and 355-425 microns were prepared. . A method proposed by Yadav and Gandhi (1992) was used to obtain dielectric properties of these samples in the temperature range 30°C to 80°C for observing their temperature variation and Two point method was used to study grain size effect on the dielectric properties of these materials.

Two-Point Method

Two point method (Bhargava *et al.,* 2013b) used to measure the dielectric properties of buckwheat. It is a technique of measurement of reflection coefficient of a solid material which is placed in a wave guide against the short circuit plunger that touches it well. To apply this method to determine dielectric properties of grains in powder form, the waveguide is bent through 90°by means of a E-plane bend. The waveguide is then terminated by a dielectric cell in which sample in powder form is filled up. This method is appropriate for low and medium loss dielectrics and can be adopted for measurement of dielectric constant and dielectric loss of food grains in powder form (Bhargava *et al.,* 2013b). In this method, the value of complex dielectric constant is given by-

$$C\angle\text{-}\psi = \frac{1}{j\beta l\varepsilon}\left(\frac{1-|\Gamma|e^{j\varphi}}{1+|\Gamma|e^{j\varphi}}\right) = \frac{\tan X\angle\theta}{X\angle\theta} \quad (1)$$

The admittance is given by

$$Y_\varepsilon = \left[\frac{x}{\beta l\varepsilon}\right]^2 \angle\, 2(\theta - 90°) = G\varepsilon + jS\varepsilon \quad (2)$$

Where G_ε and S_ε are defined as Conductance and Susceptance of the sample respectively. The value of G_ε and S_ε are determined by separating this equation in to real and imaginary parts (Bhargava *et al.*, 2013b), which provides the values of ε' and ε" in following forms:

$$\varepsilon' = \frac{G\varepsilon + (\lambda g/2a)^2}{1+(\lambda g/2a)^2} \quad (3)$$

$$\varepsilon'' = \frac{-S\varepsilon}{1+(\lambda g/2a)^2} \quad (4)$$

Where ε' is Dielectric Constant and ε" is Dielectric Loss.

A computer program in Matlab is used to solved this equation and determine the values of dielectric constant and dielectric loss.

Yadav and Gandhi Method

This method called as "Yadav and Gandhi Method" is used for studying temperature variation of dielectric properties. This method was proposed by Yadav and Gandhi (1992). In this method a constant temperature water bath is used to circulate hot water around the cell and maintain the sample at constant temperature during the experiment. The temperature of the cell could be varied from 30°C to 80°C.

For measuring the height (h) of powder in the cell, readings on micrometer screw scale are taken with food powder and without food powder in cell

During powder addition, it should be kept in mind that powder is added slowly in the cell till height 'h' for which the position of minima in the slotted section is the same as for the empty cell. For this position:

$$h = \frac{\lambda_d}{2} \text{ or } \quad \lambda_d = 2h \tag{5}$$

The value of λ_d determined by using equation (5).

The value of phase factor (β_d) in the dielectric is given by $\beta_d = 2\pi / \lambda_d$

Next step is to measure the value of dielectric's attenuation constant (α). For this, the plunger is placed at bottom of the cell and the probe is fixed around of the maxima in the slotted section, then following steps are taken: For positions of voltage antinodes in the waveguide slotted section readings 'X_1' are noted from the indicating meter. The food powder is then added slowly in the cell and position of maxima is noted each time in the slotted section. The height of powder column (h) is adjusted in such a manner so that probe position which is locating the maxima in slotted section is again at the same position as with empty cell. Then the deflection 'X_2' is noted from the indicating meter in this state for height 'h'. The value of attenuation constant is obtained from the formula given below:

$$\alpha_d = \frac{2.303}{2h'} \log \frac{\sqrt{x_1}}{2\sqrt{x_2} - \sqrt{x_1}} \tag{6}$$

Now, using the values of α_d and β_d, the values of the dielectric parameters ε' and ε'' for buckwheat grain powder are calculated using below mentioned equations-

$$\varepsilon' = \left(\frac{\lambda_0}{\lambda_c}\right)^2 + \left(\frac{\lambda_0}{\lambda_d}\right)^2 \left[1 - \left(\frac{\alpha_d}{\beta_d}\right)^2\right] \tag{7}$$

$$\varepsilon'' = 2\left(\frac{\lambda_0}{\lambda_d}\right)^2 \left(\frac{\alpha_d}{\beta_d}\right) \tag{8}$$

Where λ_o = wavelength of electromagnetic waves in free space

$\lambda_c = 2a$ = cutoff wavelength

a = width of the waveguide.

Thus the values of λ_d and α_d are calculated by using this procedure step by step as mentioned above, which when used in equations (7) & (8), provide us values of dielectric properties at different temperature.

Results and Discussion

Grain Size Dependence of Dielectric Properties of Buckwheat

The values of the dielectric constant and dielectric loss for buckwheat is reported in Table 1 for three grain sizes, viz.,90 to 150 microns, 250 to 300 microns and 355 to 425 microns at frequency 9.76 GHz in the microwave region.

From Table 1 it may be observed that the value of dielectric constant and dielectric loss of buckwheat increases with increase in grain size. (Fig.1 & 2) It may be noted that as the grain size is increased surface to volume ratio of grains decreases (Sharma *et al.*, 2010). The effect of decrease in surface area of buckwheat powder grains is to decrease reflection of electromagnetic waves, meaning thereby increase in power reaching interior of grains and hence higher probability of dipole alignment with the field (Bhargava *et al.*, 2013b). This results in the increase of dielectric parameters (ε' and ε") of buckwheat.

Table 1. Values for grain size variation of dielectric constant and dielectric loss of Buckwheat at 9.76 GHz frequency

Grain Size (micron)	Dielectric Constant (ε')	Dielectric Loss (ε")
90-150	2.15±0.06	0.19±0.01
250-300	2.37±0.07	0.19±0.01
355-425	2.67±0.06	0.21±0.01

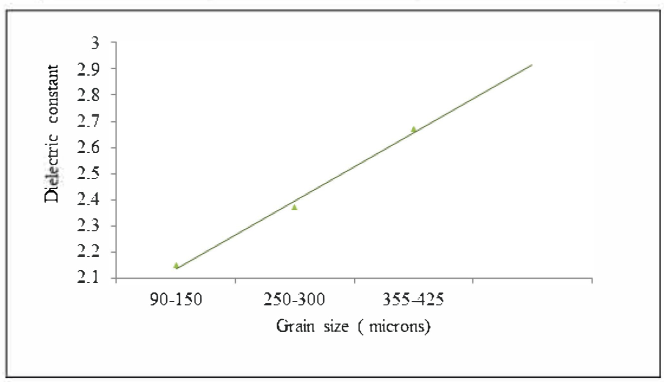

Fig. 1. Grain size dependence of dielectric constant of Buckwheat

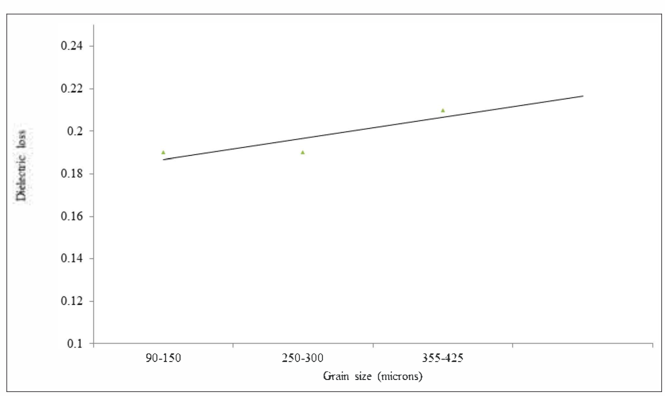

Fig. 2. Grain size dependence of dielectric loss of Buckwheat

Temperature Dependence of Dielectric Properties of Buckwheat

The values of dielectric constant and dielectric loss for Buckwheat at different temperatures are presented in Table 2. The variation of ε' and ε'' with temperature is shown in Fig. 3-4. It has been observed that both the dielectric constant and dielectric loss increase with increase in temperature.

Sahin and Sumnu (2006) observed that presence of free and bound water and the ionic conductivity affect the rate of change of dielectric constant and loss with temperature. If bound water is present, the increase in temperature leads to increase in the values of the dielectric parameters. But in the presence of free water, the increase of temperature causes a decrease in the values of the dielectric parameters (ε' and ε''). Since food grain powder is taken in dry form, it contains the moisture in bound form; hence it may cause the dielectric properties to increase with increase in temperature, which is also noted in the present case, as observed from the experimental investigations made in this study.

Table 2. Values for temperature variation of dielectric constant and dielectric loss of Buckwheat at 9.76 GHz frequency

Temperature (ºC)	Dielectric Constant (ε')	Dielectric Loss (ε'')
30	2.50±0.08	0.19±0.01
40	2.68±0.07	0.21±0.02
50	2.82±0.08	0.32±0.01
60	2.99±0.09	0.38±0.03
70	3.09±0.08	0.43±0.03
80	3.15±0.08	0.51±0.01

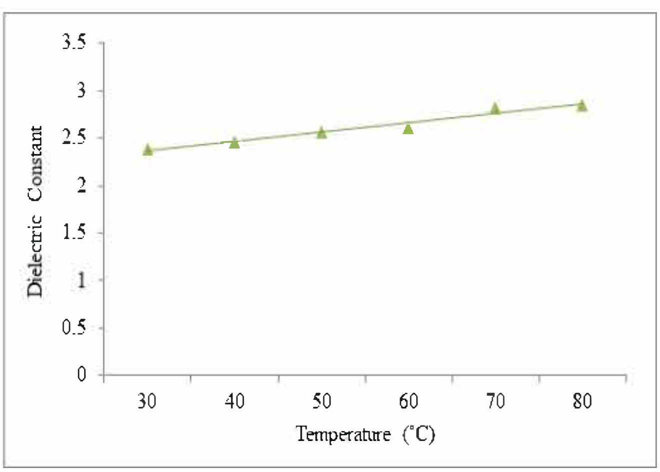

Fig. 3. Temperature dependence of dielectric constant of Buckwheat

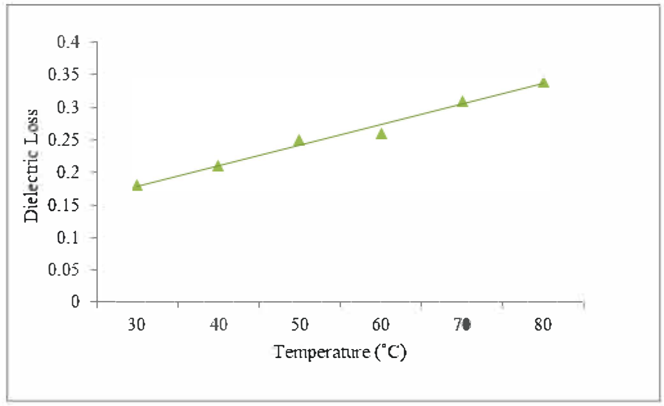

Fig. 4. Temperature dependence of dielectric loss of Buckwheat

Conclusion

It can be concluded that the dielectric properties of buckwheat vary with the change in temperature and grain size. The change in dielectric constant (ε') with temperature is small since the moisture content in these grains is in bound form. It can be inferred that both dielectric constant (ε') and dielectric loss factor (ε'') increase with increase in temperature and also increase with increase in grain size for Buckwheat. The knowledge of temperature dependence and grain size dependence of dielectric properties helps in design of microwave processes and control systems and also in material characterization.

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