ABSTRACT

Since the development of microwave procedures for communication purposes and for the study of molecular behaviour of materials, there have been tremendous development in the techniques for applications of microwaves for various purposes. For example, more efficient antennas have been developed, such as for DTH services, point to point communication - mobile communication systems, satellite communication and for communication with rocket controller vehicles etc. Impedance Analyzer and Vector Network Analyzer techniques have now become laboratory methods for rapid estimation of dielectric properties of materials in solid or liquid form. Microwave oven was invented by Percy Spencer in 1946 which has now become an essential component of every modern kitchen. It is used for more uniform volumetric heating - cooking and food processing with time saving and fuel efficiency as compared to conventional methods. It not only helps to keep the kitchen more clean but also prepares tastier recipes. Application of microwaves to agriculture and food science is comparatively new. A new branch of Physics, known as ‘Agro-Physics’, is now taking a formal status. Relationship between dielectric properties and moisture content of crops is now well established and estimation of moisture in materials or crops through the measurement of their dielectric properties is a sub branch of Agro Physics, known as ‘Aquametry’.

The dielectric properties of crops and agricultural products are important as they provide information about moisture level of crops. This knowledge helps in deciding whether the crop is safe for storage. If the moisture level of the crop is higher, it is more likely to get spoiled by fungi. Microwaves can be used for disinfestation of grains by selective heating. The process of microwave heating is now also used in warehouses to save the stored grains from being spoiled by insects.

Dielectric properties of a material are those intrinsic electrical properties that provide information about how electromagnetic radiation interacts with the material. In food materials such interactions are more prominent at microwave frequencies and as such the novice method of cooking by microwave oven has become a reality. The knowledge of the dielectric properties of food materials is important since it
helps in understanding and predicting their interaction with electromagnetic field, at desired frequencies. During the recent years, many potential applications of electromagnetic heating of foods have come up and have been published in the literature; however, new methods or research on food products treated by microwaves are still limited due to lack of adequate dielectric data. Knowledge of dielectric properties has been used both for research purposes; to better understand the structures, composition and behaviour of foods, as well as in commercial applications, viz, dielectric heating, microwave drying and controlling different parameters in food processing. Accurate measurements of dielectric properties can provide scientists and engineers with valuable information which helps them to properly incorporate the material into its intended application.

The knowledge of dielectric properties and their dependence on frequency of radiation and physical properties such as, temperature, density, grain size and composition is necessary for understanding and analysis of microwave heating of food and biological materials. The knowledge of these properties is considered essential in the design and construction of microwave ovens; in selection of proper heating equipments and cooking utensils; for selection of packaging materials, and in developing, processing or formulating food recipes.

Looking into the range of applications of dielectric properties of foods, limited availability of dielectric data of various ingredients of food, and vast scope of studies in this field, dielectric properties of food grains, pulses and oilseeds at microwave frequencies have been investigated in the present study. The objectives set for this research were:

- To study dielectric properties of cereals and grains in powder form
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- To study dielectric properties of pulses and legumes in powder form. (any one)
- To study dielectric properties of nuts and oilseeds in crushed form. (any one)
- To study the effect of frequency variation (in microwave region) on the dielectric properties of selected food samples.
- To study the effect of temperature variation in the representative cases.
• To determine dielectric properties of solid materials using dielectric mixture equations.
• To estimate nutrients (moisture, proteins, fats, fibre, ash content and total carbohydrates) of selected food samples.
• To correlate dielectric properties of selected food samples and their nutrients.

Thus, the main objective of the present research was to investigate the dielectric properties, i.e., dielectric constant ($\varepsilon'$) and dielectric loss factor ($\varepsilon''$) of food grains, pulses and oilseeds at microwave frequencies. The effect of frequency variation, moisture content variation and temperature variation on dielectric properties was also investigated on the dielectric properties in the representative cases.

Research was carried out at The IIS University microwave lab keeping in mind the above mentioned objectives decided by the Departmental Research Committee. Most of the samples needed for the present research were obtained from Agriculture Research Station, Durgapura, Jaipur of Swami Keshavanand Agriculture University, Bikaner and the samples of different varieties of mustard seeds were obtained from National Mustard Research Centre, Sewar, Bharatpur.

The research work done is presented in the thesis in the form of nine chapters.

Chapter 1 contains an introduction to microwaves, microwave heating, general idea and principles of the dielectric dispersion and relaxation mechanism along with applications of dielectric measuring techniques.

The present research is aimed on investigating dielectric properties of food grains, pulses and oilseeds at microwave frequencies. As such, in chapter 2, a review of the previous research on dielectric properties of the aforesaid materials is presented along with recent advancement in techniques of dielectric properties estimation. A review on the influence of frequency, temperature, moisture content, composition and density variation on dielectric properties ($\varepsilon'$ and $\varepsilon''$) is also presented.
Chapter 3 gives an overview of the microwave measurement techniques. This chapter provides an information about the most commonly used microwave measurement techniques employed for measurement of the dielectric properties of the food and agricultural products, viz., open ended coaxial probe method, transmission line method, resonant cavity method and free space measurement method. This chapter also reviews the advantages and disadvantages of these measurement techniques employed for various types of food products.

Out of various techniques generally used for measurement of dielectric properties, the transmission line method using the waveguides has been employed in the present research work, which is a laboratory method and preferred for its simplicity, convenience and accuracy. The methods used in this research are 1) Two point method (Sucher and Fox, 1963; Behari, 2005) and 2) Yadav Gandhi method (1992) which are particularly suitable for samples in powder form.

An introduction to dielectric mixture equation is also presented in this chapter. The nutrients of food grains analyzed and the methods used for the same in the present study are: moisture by oven drying method, proteins by Micro Kjeldal method, fats by ether extraction method, ash and crude fibre by acid alkali method and the carbohydrates by the difference method.

In Chapter 4, dielectric constant ($\varepsilon'$) and dielectric loss ($\varepsilon''$) values for the following samples of food grains, pulses and oilseeds in powder form obtained by using two point method are reported at four different frequencies, viz., 4.65 GHz, 7.00 GHz, 9.35 GHz and 14.98 GHz.

i. Cereals and grains: Wheat, Rice, Barley, Pearl Millet, Sorghum

ii. Pulses and legumes: Chickpea, Green gram

iii. Nuts and oilseeds: Mustard seeds, Soybean

For the sake of comparison of dielectric properties of wheat in powder and whole grain form, the dielectric properties of wheat are also determined in whole grain form by using the two point method and dielectric mixture equations are used to calculate dielectric properties of solid mass of wheat. It can be inferred that both, dielectric constant ($\varepsilon'$) and dielectric loss factor ($\varepsilon''$) of food grains, pulses and
oilseeds decrease with increase in frequency, showing that these materials exhibit dielectric dispersion at microwave frequencies

The effect of moisture content on the dielectric properties of wheat, pearl millet and green gram has been investigated at the four frequencies, viz., 4.65 GHz, 7.00 GHz, 9.35 GHz and 14.98 GHz and the results obtained are presented and discussed in chapter 5. The values of ac conductivity (σ) and relaxation time (τ) evaluated from the dielectric properties of three samples are also reported at the four frequencies. It has been observed that for all the four frequencies, values of dielectric constant (ε') and dielectric loss factor (ε'') increase with increasing level of moisture content in all the three samples, viz., wheat, pearl millet and green gram.

In chapter 6 the results of the effect of temperature variation (from 30°C to 80°C) on dielectric properties of barley, chickpea and mustard seeds at frequencies 4.65 GHz, 7.01 GHz and 9.42 GHz have been reported. The temperature variation has been studied for the above samples in powder form by using the method proposed by Yadav and Gandhi (1992). It has been observed that both the dielectric constant (ε') and dielectric loss (ε'') of barley and chickpea show slight increase in their respective values with increase in temperature. The behaviour of mustard seeds with increase in temperature is also discussed.

The frequency dependence of dielectric properties of wheat (RAJ 4120 variety) is presented in chapter 7. Dielectric properties of wheat were investigated in powder form by employing Yadav Gandhi method in C, X and Ku bands of microwave frequencies, respectively at 4.70, 9.39 and 14.15 GHz. The dielectric parameters of solid mass of wheat were obtained by employing dielectric mixture equations. The results obtained for ε' and ε'' of solid mass of wheat are compared with the values reported by Nelson by employing network analyzer technique.

In chapter 8, the effect of grain size on the dielectric properties of five varieties of wheat viz., LOK 1, UP 2382, RAJ 3765, RAJ 2384 and Sharbati is reported. Wheat samples of three grain sizes, i.e., 355-425 microns, 250-300 microns and 90-150 microns were used for determination of their dielectric
properties at 9.42 GHz frequency, by using two point method, by employing a X-band microwave bench along with a specially designed sample holder for powders. Effect of frequency variation and the grain size effect for three varieties of wheat (viz., LOK-1, UP 2382 and RAJ 2384) have also been investigated by taking wheat powder at the above mentioned three grain sizes and performing measurements at frequencies 7.00, 9.42 and 14.92 GHz. Grain size effect was also investigated for the powders of chickpea and rice, for the sake of a comparative study of dielectric properties of the three types of grains, viz., chickpea, rice and wheat, so as to derive generalized conclusions. It was concluded that both the dielectric constant ($\varepsilon'$) and loss factor ($\varepsilon''$) depend on the density of the wheat flour for all the five samples, the values of both of them increasing with increase in density.

The values of food nutrients of certain cereals, pulses and oilseeds as obtained by standard techniques of nutrient estimation are presented in chapter 9. Along with an introduction to correlation analysis, the values of correlation coefficient obtained between the dielectric properties of food grains and their nutrients, as determined by using SPSS software, are presented in this chapter.

Results of correlation analysis show that dielectric properties ($\varepsilon'$ and $\varepsilon''$) of cereals and pulses show significant correlation with certain nutrients at particular frequencies and may be used as indicators for such nutrients.

It can be concluded that dielectric properties of a typical food material depend on a number of factors and cannot be easily predicted just by its proximate analysis and knowledge of composition. The reasons which make the composition – based predictions of dielectric properties of foods so difficult are that the molecular structures and chemical compositions of the nutrients are quite complex and susceptible to different physical conditions, whose effects differ for different nutrients and that both non electrolyte and electrolyte systems play an important role in determining the dielectric behaviour of foods.

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