

Correlations of Complex Dielectric Constant of Tree Leaves with Their Chemical Properties at X-Band Frequency

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ABSTRACT: The main objective of this study is to measure the dielectric and chemical properties of tree leaves and to find out the statistical correlation factor between them. The complex dielectric constant of the tree leaves samples are measured using wave-guide cell method. An automated X-band microwave set-up in the TE₁₀ mode with Gunn source operating at frequency 10.63 GHz is used for this purpose. Results were analyzed statistically, which showed positive and negative correlation coefficients for dielectric constant and loss with chemical content for all the six samples studied. Besides agricultural applications, such studies may find importance in remote sensing applications in agriculture and forestry and also for analyzing the satellite data in remote sensing.

KEYWORDS: Dielectric constant, loss, Tree leaves, chemical parameters, correlation coefficient

I. INTRODUCTION

Water is one of the most common and most important substances on the earth's surface. It is the most significant single environmental factor that determines the kinds and amounts of vegetation cover on various parts of the globe. Vegetation has physical, chemical as well as electrical properties. Shape, size, structure, etc., comprise the physical properties; sodium, potassium, calcium, magnesium, iron, protein, manganese, fiber, silica, phosphorus, ash, carbon, and nitrogen, fat, carbohydrate etc., comprise chemical properties while, electrical properties include dielectric constant, electrical conductivity and permeability.

Trabelsi S. and Nelson S. [1] have outlined different techniques for determining the dielectric properties of biomaterials to estimate water content. According to Von Hippel A. R. [2], dielectric properties represent a measure of the polarizability of a material when subjected to an electric field. Experimental studies on the microwave dielectric behaviour of vegetation material have been reported by Chukhlantsev A. A. and Golovachev S.P. [3], El-Rayes M. and Ulaby F.T. [4], Kirdyashev K. P. and Chukhlantsev K. P. [5], El-Rayes M. and Ulaby F.T. [6] and also by several other investigators [7,8,9]. Their results have shown the strong dependence of attenuation by vegetation on microwave frequencies. Chuah H. T. et al. [10] have reported the dielectric constants of leaves of two tropical crops, as a function of moisture content at X-band frequency. Measurements of dielectric constant of Neem leaves from deserted areas at X-band frequency were carried out Calla OPN, et al. [11]. They have estimated the values of emissivity and scattering coefficients of neem trees and outlined their importance for designing passive and active sensors required in microwave remote sensing of vegetation canopies.

Some of the investigators [12-18] have attempted the studies on statistical correlations of dielectric constant and electrical conductivity with physico-chemical properties of soils having different colours and textures. From such study the prediction of the micro and macro nutrient concentration in soils and/or physical characteristics of soils are possible. Further, Calay et al. [19], Guan et al. [20], Sun et al. [21], Tabil L. G. [22], Nidhi Bharagava [23] have made attempts to express dielectric properties as a function of processing variables and chemical composition. These attempts include modelling a single food item, as well as a combined data of a wide range of food commodities.

However, to our knowledge, so far, almost no or very rare studies have been attempted on correlation between dielectric properties of vegetables/tree leaves with their chemical contents/nutrients. Therefore, in the present investigations we have made the measurements of dielectric constant and dielectric loss of tree leaves samples

and attempted to study statistical correlation factor with their chemical contents. Tree leaves species samples are collected from North Maharashtra region. The dielectric constant of tree leaves samples are measured at X-band microwave frequency, 10.63 GHz, by waveguide cell method using automated microwave set-up.

II. MATERIALS AND METHODS

Samples and their preparation

We have plucked fresh six different medicinal tree leaves samples from North Maharashtra region of Maharashtra state. Initially, these tree leaves samples are inserted into the solid dielectric cell for measuring their dielectric constant. Samples are reshaped/cut according to their length 2.286cm X 1.016cm cross sections for X-bands. Sample lengths are taken in the multiples of $\lambda/4$. Then the gravimetric moisture content (wet basis) of the tree leaves sample will be gradually reduced by drying it in a hot air oven at 50° to 60° C. Moistures (wet-basis) of leaves are varied from its natural to oven dry value. The single pan precision balance having digital readout accuracy of 0.1 mgm is used for weighing the sample. Proper care was taken to expose the moist tree leaves to the atmospheric air as little as possible.

Measurement of Dielectric Constant of Tree Leaves

The dielectric properties of these tree leaves samples are measured using wave-guide cell method. An automated X -band microwave set-ups in the TE₁₀ mode with Gunn source operating at frequency 10.63 GHz in X -band, is used for this purpose. Automation of this set-up includes PC-Based slotted line control and data acquisition system. The main advantages obtained due to automation are increased resolution of output, reduction of backlash error in slotted line, visual representation of standing wave pattern. The sample lengths are usually taken in the multiples of $\lambda/4$. It is a very important parameter and inaccuracy in its measurement may lead to serious errors. The solid dielectric cell with tree leaves sample is connected to the opposite end of the source. The signal generated from the microwave source is allowed to incident on the tree leaves sample. The tree leaves sample reflects part of the incident signal from its front surface. The reflected wave combined with incident wave to give a standing wave pattern. These standing wave patterns are then used in determining the values of shift in minima resulted due to before and after inserting the sample. The dielectric constant of tree leaves is calculated by measuring the standing wave ratio of the dielectric material and the shift in minima of the standing wave pattern in a rectangular waveguide. This shift takes place due to change in the guide wavelength when a dielectric material is introduced in waveguide. By substituting these values of shift in minima, VSWR, waveguide dimensions, guide wavelength, etc., in a well designed computer programs, the values of dielectric constant of tree leaves are determined. In order to improve the accuracy of these results, average of several readings is taken. The dielectric constant (ϵ') and dielectric loss (ϵ'') of the tree leaves is then determined from the following relations:

$$\begin{aligned} &\text{Dielectric constant } (\epsilon') \\ \epsilon' &= \frac{g_{\epsilon} + (\lambda_{gs}/2a)^2}{1 + (\lambda_{gs}/2a)^2} \end{aligned} \quad \text{----- (1)}$$

$$\epsilon'' = - \frac{\beta_{\epsilon}}{1 + (\lambda_{gs}/2a)^2} \quad \text{----- (2)}$$

Where, a = inner width of rectangular waveguide
 λ_{gs} = wavelength in the air-filled waveguide
 g_{ϵ} = real part of the admittance
 β_{ϵ} = imaginary part of the admittance

Chemical properties of tree leaves

The chemical compositions/nutrients of the leaves are usually related to the soil conditions and the tree species selected. The tree leaves species have chemical contents like sodium, potassium, calcium, magnesium, iron, protein, manganese, fiber, silica, phosphorus, ash, carbon, and nitrogen, fat, carbohydrate, etc.. The chemical contents/nutrients of the tree leaves samples studied here are presented in **Table 1**. These chemical contents/nutrients were measured in the Shree analytical testing and research laboratory, Jalgaon. All these chemical parameters/properties were measured by using standard methods.

Table 1: Chemical properties of tree leaves samples

Statistical Analysis:

The relationship between different trees leaves parameters and chemical content of tree leaves weredetermined using correlation coefficient “r”.

Sample No. (Name)	Chemical contents in tree leaves samples							
	Total Ash gm%	Protein gm%	Fat gm%	Calcium mg/100gm	Phosphorous mg/100gm	Fiber gm%	Iron mg/100gm	Carbohydrate gm%
S1. Amla (Emblica officinalis)	4.50	6.90	3.91	50.0	0.00	3.80	1.33	82.7
S2. Babul (Acacia nilotica)	19.50	18.50	3.31	58.0	20.2	30.3	15.5	56.60
S3. Imli (Tamarindus indica Linn.)	10.65	1.68	4.32	70.0	16.5	6.10	2.68	82.20
S4. Neem (Azadirachta indica)	4.50	16.20	2.88	80.2	73.30	3.44	4.60	67.88
S5. Nilgiri (Eucalyptus citriodora)	10.50	12.20	0.82	100	0.52	20.2	2.33	76.0
S6. Sagwan (Tectona grandis)	14.88	26.60	4.90	115.0	0.00	22.2	20.0	52.0

$$r = \frac{n \sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2} \sqrt{n(\sum y^2) - (\sum y)^2}} \text{-----(2)}$$

Where *n* is the number of pairs of data (x, y).

III. RESULT AND DISCUSSION

For any vegetation or plants its chemical nutrient contents are very important. If the vegetation lacks adequate quantities of nutrients, vegetation/plants may become unhealthy and die. In order to find the status of available contents in tree leaves, it becomes necessary to know their co-relations with dielectric constant and dielectric loss.

Correlation between dielectric properties of vegetables/tree leaves with their chemical contents, viz., ash, protein, fat, calcium, phosphorus, fiber, iron and carbohydrate etc., have not been investigated till date. In the present research work, we have tried to correlate and find out correlation coefficient between dielectric properties (dielectric constant and loss) measured at of six different tree species with their chemical nutrients.

Correlation of dielectric constant of tree leaves with nutrients

Results on correlations of dielectric constant with chemical contents/nutrients in tree leaves are graphically shown Fig.1 (a-h) at X-band (10.63GHz)microwave frequency. Correlation coefficients of dielectric constant of these tree leaves at microwave frequencies with their chemical contents/nutrients are summarized in **Table 2**.

From Fig.1 (a-h), it is found that fat content of leaves samples do not show any co-relation ($R_x=0.00$) with dielectric constant at X-band; whereas, ash ($R_x=0.268$), fiber ($R_x=0.2258$) and carbohydrate ($R_x=0.3962$) contents show moderately positive correlations. Further, the results also indicate a strong negative correlation of dielectric constant with phosphorous ($R_x=-0.7549$) and with protein ($R_x=-0.4893$), iron ($R_x=-0.1897$) and calcium($R_x=-0.4888$) it isrelatively less negative.

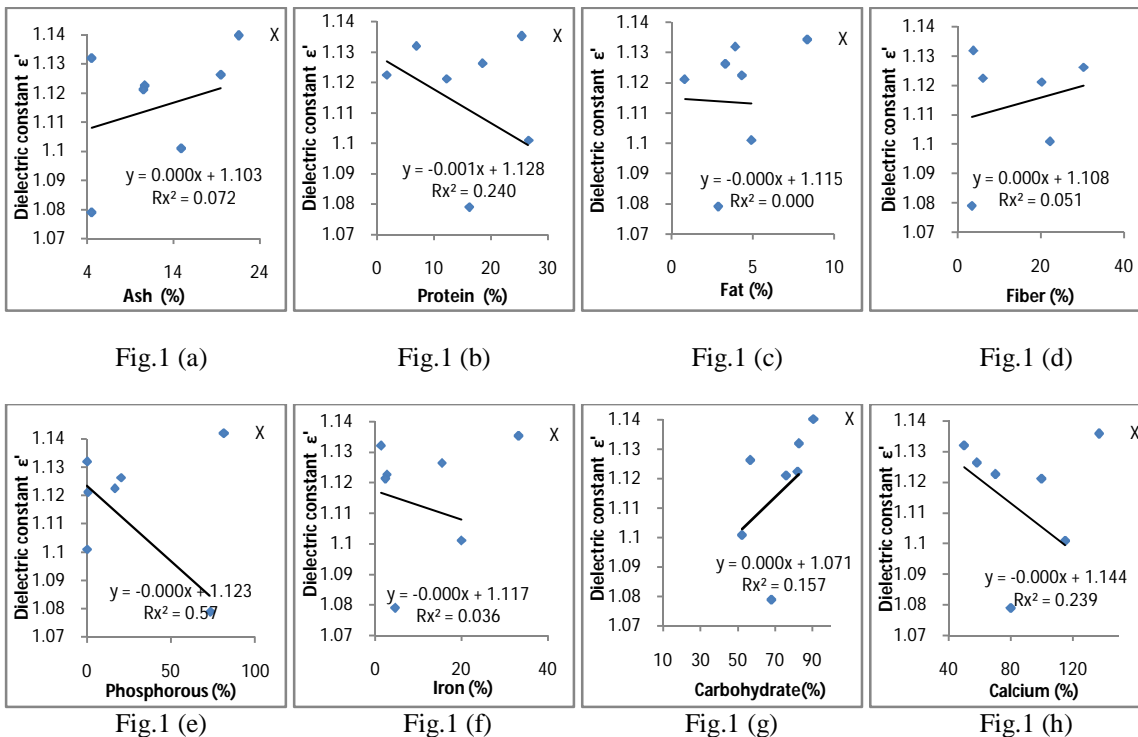


Fig.1 Variation of Dielectric Constant with nutrient of tree leaves samples (S1-S6) a X-band (10.63GHz)

Correlation of dielectric loss of tree leaves with nutrients

Results on correlations of dielectric loss with chemical contents/nutrients in six tree leaves samples are graphically shown Fig.2 (a-h) at X-band (10.63GHz)microwave frequency. Correlation coefficients of dielectric loss of these tree eaves at microwave frequencies with their chemical contents/nutrients are summarized in **Table 2**.

Results on correlations of dielectric loss with chemical contents/nutrients in six tree leaves samples are graphically shown Fig.2 (a-h) at X-band (10.63GHz)microwave frequency. Correlation coefficients of dielectric loss of these tree eaves at microwave frequencies with their chemical contents/nutrients are summarized in **Table 2**.

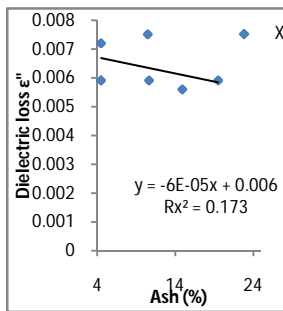


Fig.2 (a)

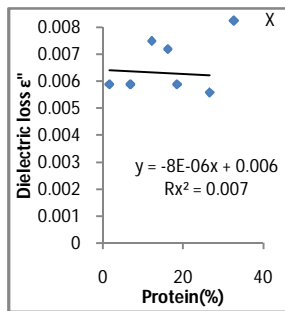


Fig.2 (b)

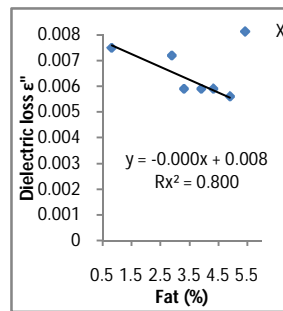


Fig.2 (c)

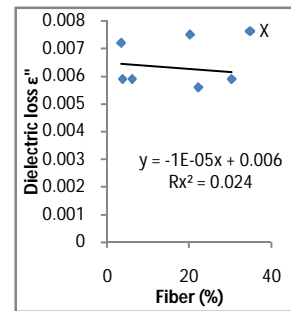


Fig.2 (d)

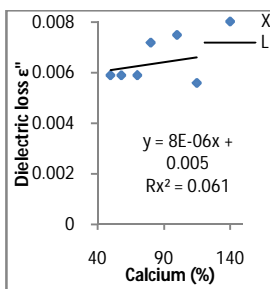


Fig.2 (e)

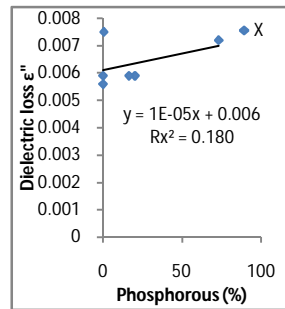


Fig.2(f)

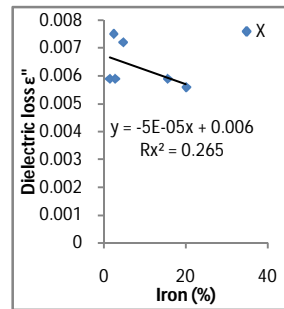


Fig.2(g)

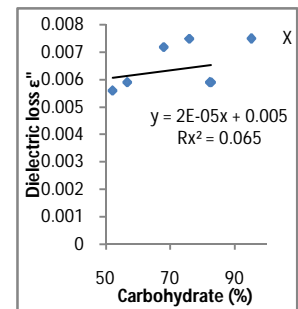


Fig.2(h)

Fig.2 Variation of Dielectric Loss with nutrient of tree leaves samples (S1-S6) at X-band (10.63GHz)

Fig.2 (a-h) shows moderately positive correlation of dielectric loss of tree leaves samples at X-band frequency with chemical content/nutrient such as calcium ($R_x=0.2469$), phosphorous ($R_x=0.4242$) and carbohydrate ($R_x=0.2549$); whereas it has strongly negative relationship with fat ($R_x=-0.894$), moderately negative with ash ($R_x=-0.4159$) and iron ($R_x=-0.5147$) and for protein ($R_x=-0.0836$) and fiber ($R_x=-0.1549$) it has weakly negative correlation.

IV. CONCLUSIONS

Results of our study for statistical correlation coefficient for dielectric constant and dielectric loss of six tree leaves samples at X band microwave frequency with their chemical properties as discussed in earlier are summarized in **Table 2**.

Table 2: Correlation coefficient of dielectric constant and dielectric loss for tree leaves samples (S1-S6) with their chemical content

Tree leaves Parameter	Statistical Correlation Coefficient			
	Dielectric Constant		Dielectric Loss	
	$R_x(X\text{-band})$	R^2_x	$R_x(X\text{-band})$	R^2_x
Correlation with				

Correlation with Tree leaves Parameter	Statistical Correlation Coefficient			
	Dielectric Constant		Dielectric Loss	
	$R_x(X\text{-band})$	R^2_x	$R_x(X\text{-band})$	R^2_x
Total Ash (gm%)	0.268	0.072	- 0.4159	0.173
Protein (gm%)	- 0.4893	0.240	- 0.0836	0.007
Fat (gm%)	0.000	0.000	- 0.894	0.800
Calcium (mg/100gm)	- 0.4888	0.239	0.2469	0.061
Phosphorous (mg/100gm)	- 0.7549	0.57	0.4242	0.180
Fiber (gm%)	0.2258	0.051	- 0.1549	0.024
Iron (mg/100gm)	- 0.1897	0.036	- 0.5147	0.265
Carbohydrate (gm%)	0.3962	0.157	0.2549	0.065

From **Table 2**, we observe positive statistical correlation coefficient for dielectric constant of six tree leaves samples at X band microwave frequency with their fat, fiber and carbohydrate contents while negative statistical correlation coefficient with protein, fat and iron contents; whereas chemical contents such as calcium and phosphorous have mixed trends for statistical correlation coefficient with dielectric constant.

Further, from **Table 2**, we observe positive statistical correlation coefficient for dielectric loss of six tree leaves samples at X microwave frequency with their carbohydrate contents while negative statistical correlation coefficient with protein, fat and iron contents; whereas chemical contents such as fat, fiber, calcium and phosphorous have mixed trends for statistical correlation coefficient with dielectric loss.

Results of this kind will not only have lot of importance in remote sensing applications in agriculture and forestry but also useful in determining the chemical compositions of vegetation. Thus, by analysing the satellite data of desired region and knowing the significant correlations along with regression equations of dielectric constant and dielectric loss of various tree leaves with their chemical properties, we can obtain the useful information about the status of available nutrients of tree leaves/vegetation. In short, dielectric properties will indicate the nutrients types and their levels in the vegetation.

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