Study of Dielectric Constant and Loss Factor for Three States of Grains Using Microwave Frequency (CJ-Band) Using the Waveguide Method

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ABSTRACT

This paper represents the study of dielectric constants along with their loss factor for various kinds of grains, which further define their responses against electromagnetic energy at different microwave frequencies by absorbing, emitting, reflecting, and scattering a portion of electromagnetic energy. Measurement of dielectric constant and loss factor have made for various samples of grains such as Rice, Wheat, Split Red Gram (Arhar), Bengal Gram (Chana), Green Gram (Moong) for three different states as preliminary, oven dried and saturated at different gravimetric moisture content in range of CJ Band at two different frequency values (5.30 and 6.60 GHz) by using waveguide cell (short circuited lines or double minima or two point) method. The general laboratory statistics are equally significant in identifying the grains and relatively increase the characterized crop productivity by using microwave remote sensing applications. The analytical study of different cereals and pulses at microwave frequencies may provide information about the vegetation area and also help to detect their behavioral properties. It was an early experimental study relevant to current grain moisture characterization and RF applications. This paper presents an experimental analysis of the dielectric constant and loss factor for five cereal and pulse grains—Rice, Wheat, Split Red Gram (Arhar), Bengal Gram (Chana), and Green Gram (Moong)—under three distinct moisture conditions: preliminary, oven-dried, and saturated. Using the two-point waveguide method, measurements were taken at microwave frequencies of 5.30 GHz and 6.60 GHz (CJ-band). The work reveals significant variation in dielectric behavior across moisture levels and frequency bands, demonstrating a strong correlation between dielectric response and gravimetric moisture content. The findings contribute valuable data for applications in microwave remote sensing, grain moisture estimation, and agricultural material characterization.

Keywords: dielectric constant; gravimetric moisture content; waveguide cell; preliminary; oven dried; saturated; microwave remote sensing; CJ Band; vegetation.

INTRODUCTION

The dielectric properties of agricultural materials are crucial in applications ranging from moisture sensing and grain classification to RF heating and remote sensing. The complex relative permittivity, expressed as

$$\epsilon = \epsilon' - j\epsilon'' \qquad (1)$$

Quantifies how materials interact with electromagnetic energy. The real part ϵ' (dielectric constant) is related to energy storage, while the imaginary part ϵ'' (loss factor) captures energy dissipation. For biological materials such as grains, these parameters are functions of frequency, temperature, moisture content, and bulk density.

This study aims to experimentally measure the dielectric properties of five cereals and pulses using the two-point short-circuited waveguide method. Unlike invasive probe-based techniques, the waveguide approach used here provides relatively consistent results for granular media under controlled physical states. This research was done,

and the data were collected in May 2013. The motivation stems from the need for reliable dielectric data of the CJ band regions for remote sensing and food processing applications.

The dielectric properties of many materials depend on frequency, moisture content, bulk density, temperature, chemical composition, and permanent association of dipole moments with water and other constituent molecules [1] [2]–[7]. The dielectric properties of agricultural or biological materials are of great importance in the processing of agricultural commodities and food. The concept and idea about the dielectric properties of agricultural commodities enable us to understand the interactions between electromagnetic waves and vegetation, to inspire the development of RF treatments for agricultural products. [8] [9]

In granular and particulate materials such as cereals and grains, the bulk density of the mixture of particles and air is another factor that influences the permittivity. [8] [10]

Therefore, there is a significant need for analytical expressions that describe the dielectric properties of different types of grain at particular frequencies as functions of density and moisture content. [11] This attenuation is due to the scattering and absorption of the transmitted wave as it propagates through areas of vegetation [12].

Generally, both the dielectric constant and the loss factor show monotonic decreases in value as frequency increases. Temperature and moisture content cause variations in the value of the dielectric constant for different frequencies. At lower frequencies, the dielectric constant (conductivity) increases with the temperature, but it is not so for higher frequencies, whereas for the loss factor, it is more variable with the temperature. Researchers have tested different techniques of using the dielectric properties of biomaterials to estimate the water content present in the cereal. These studies include transmission line techniques such as waveguide (coaxial and free-space), impedance, and cavity methods.

MEASUREMENT OF DIELECTRIC CONSTANT
A. Maintaining the Integrity of the Specifications
When microwaves are applied to any material, one part of the energy is reflected, one part is transmitted through the surface of the granular elements of the material, and part of it is absorbed by it. The fundamental electrical property through which the interactions are described is the complex relative permittivity of the material. [14]

I.

Dielectric constant for the lossy medium can be formulated as:

$$\epsilon_r = \epsilon'_r + \sigma/j\omega\epsilon_0 \qquad (2)$$

$\sigma = \omega\epsilon_0\epsilon''$ = Dielectric conductivity in Siemens per meter (sums overall dissipative effects of the grains)
ϵ'_r = real valued permittivity = Dielectric Storage Factor
$\omega = 2\pi/\lambda = 2\pi f$ = angular frequency (f in Hz)
$\epsilon_0 = 1/(\mu c2) = 8.854 \times 10^{-12}$ F/M permittivity of free space reduces to:

$$\omega\epsilon_r = \epsilon'_r - j\sigma\lambda k$$

Here,
k = $\mu_0 c/2\pi$
j = $\sqrt{-1}$
$\sigma\lambda k = \epsilon''_r$ = Dielectric Loss Factor So,

$$\epsilon_r = \epsilon'_r - j\epsilon''_r = |\epsilon'|e - j\delta \quad (3)$$

δ - Loss angle of dielectric i.e., tan $\delta = \epsilon''/\epsilon'$ is the tangent loss or dissipative factor.
r - Is the subscript used for simplification in the remainder of this article.

The real part of the permittivity represents the energy storage capability in the electric field of the dielectric material, and the imaginary part represents the energy dissipation capability of the dielectric by which energy from the electric field is converted into heat energy in the dielectric.

In RF treatments, electromagnetic energy interacts directly with commodities containing polar molecules and charged ions to generate heat. The way in which any material interacts with electromagnetic energy may be described by its dielectric properties. Dielectric properties have been reported for different frequency ranges, Sample Grains: Cereals and Pulses. The present study investigates the dielectric behavior of five commonly consumed grains: Wheat (*Triticum aestivum*), Rice (*Oryza sativa*), Arhar or Split Red Gram (*Cajanus cajan*), Chana or Bengal Gram (*Cicer arietinum*), and Moong or Green Gram (*Vigna radiata*). These samples were analyzed under varying moisture content and frequency conditions to assess their dielectric constant and loss factor characteristics.

a) Wheat: the grain of any cereal grass of the genus Triticum, with moist, dry weather conditions, grown in clay and loamy soil, used for culinary and nutritional purposes.
b) Rice: a cereal grass that is cultivated extensively in warm climates in areas having heavy rainfall for its edible grain.
c) Green Gram: well known as Moong is a Kharif crop grown in the moist summer season.
d) Split Red Gram: grown in the summer season, cultivated during warm tropical and subtropical climates, requires fertile soil.
e) Bengal Gram: requires irrigation and grows in less heavy soil texture, having drainage and rainy conditions in the winter season.

MATERIALS AND METHODS
Sample Preparation
Sample preparation has been done in three different stages, which define the moisture content or presence of water in cereals.
(1) Preliminary sample
(2) Oven-dried sample
(3) Saturated sample
During sample preparation, the same sample only, of different varieties of grains undergoes all three different physical states (i.e. of preliminary, oven-dried, and saturated states) successively.
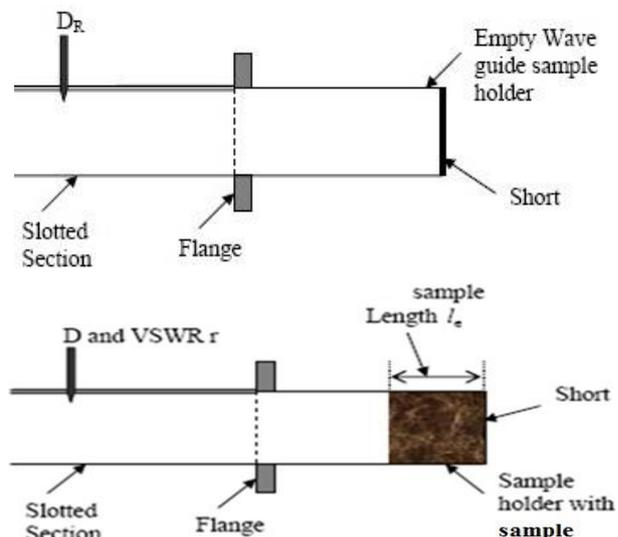

FIGURE 1: Two different stages of the waveguide without and with a sample.

Method used

The most widely used and versatile microwave measurement technique is the two-point method of measuring the complex dielectric constant, involving the solution of a transcendental equation. The input impedance of a short-circuited waveguide is measured with and without the sample, and a transcendental equation is solved. This method is very simple but may lack accuracy depending on the exact sample length. Further, for the dry and wet samples, which are non-homogeneous medium having grain particles, air voids, and water, it is difficult to arrange the samples uniformly with the same density profile in the total length of the sample holder waveguide. The two-point method is best known and most widely used for the measurement of complex permittivity. It is best suited to either "lossless" dielectrics or dielectrics with medium loss. Figure 1 shows an empty short-circuited waveguide with a probe located at a voltage minimum.

Figure (4.1-b) shows the same waveguide, containing a sample of length l_ϵ, with the probe located at a new voltage minimum Dr. the sample is adjacent to the short circuit. It should be noted that the accuracy of the experimental results of complex permittivity using this method depends to a large extent on the smoothness of the sample, the fitting of the sample in the waveguide, the care which has been taken to insure that its surfaces are properly "squared" with respect to each other, the accuracy of measurement of length l_ϵ of the sample, the position of minima Dr and D and the accuracy in the measurement of VSWR i.e. voltage standing wave ratio. The estimation of the dielectric constant has been made using the measured values of dielectric constant using the two-point method at three microwave frequencies of the CJ-band (5.30 and 6.60 GHz). Since dielectric properties are also dependent on the temperature and bulk density, or test weight, of grain and seed samples, corrections must be made for deviations of either variable to avoid errors in moisture readings. For the moisture content, we used distilled water as its complex permittivity is known.[17]

FIGURE 2: Calibrated sample weighing machine.

FIGURE 3: Set up for measurement of dielectric constant at CJ- Band (3.95-5.85 GHz).

The method used in the measurement of the dielectric constant of a solid material, like cereals is based upon basic fundamentals of microwave equipment.

In this waveguide cell method, the dielectric constant is measured by calculating the shift in minima of the standing wave pattern in a rectangular waveguide. This shift takes place due to the change in the guide wavelength when a dielectric material is introduced in the waveguide.[18] Here, the measurement of guide wavelength is carried out at three microwave frequencies.

TABLE 1: Analyzed frequency band.

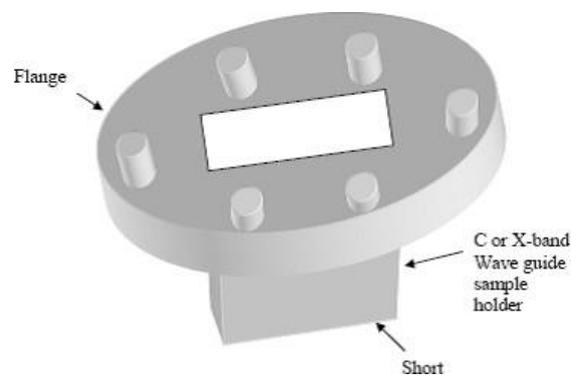| Band	Frequency (GHz)
CJ-Band	5.3 GHz
CJ-Band	6.6 GHz

FIGURE 4: Sample Holder (CJ-Band).

The relevant equations used for determining the dielectric constant at the given frequencies are as follows:

$$k = 2\pi/\lambda_g \qquad (4)$$

Where,
k= Propagation constant
λ_g = Guide wavelength

$$\Phi = 2k(D - D_r - l_\epsilon) \quad (5)$$

Where,
ϕ = Phase angle
D = First voltage minima of the sample
D_r = First voltage minima when the waveguide is short-circuited.
l_ϵ = length of sample

TABLE 2: Units and corresponding symbols.

Band	Length of the Sample (cm)
CJ-Band	0.694

$$|\Gamma| = \frac{(r-1)}{(r+1)} \qquad (6)$$

Where,
$|\Gamma|$ = reflection coefficient
r = voltage standing wave ratio (VSWR)

Complex transcendental equations:

$$A = (|\Gamma|^2 - 1)/\left(kl_\epsilon(1 + |\Gamma|^2 + 2|\Gamma|cos\phi)\right) \quad (7)$$

$$K = \frac{-2|\Gamma|\sin\phi}{kl_\epsilon(1+|\Gamma|^2+2|\Gamma|\cos\phi)} \quad (8)$$

Now, solve for X in the real transcendental equation, using the two sets of data to determine X'

$$R = \frac{AX'^2}{\tan X' - X'(1+\tan^2 X')} \quad (9)$$

$$K' = \frac{R\tanh[R(1+\tan^2 X')+X'\tan X'(1-\tan^2 hR)]}{(R^2+X'^2)(1+\tan^2 R \cdot \tan^2 X')} \quad (10)$$

If K and K' are almost identical, the values of X' and R calculated are acceptable; if not, this method of solution does not apply.

$$T = \sqrt{R^2 + X'^2} \quad (11)$$

$$\tau = \tan^{-1}\left(\frac{X'}{R}\right) \quad (12)$$

Where,
$45° < \tau < 90°$

$$\gamma_e = \left(\frac{T}{kl_\varepsilon}\right)^2 < 2(\tau - 90°) \quad (13)$$

$$\gamma_e = G_e - jB_e \quad (14)$$

Where,
γ_e = admittance
G_e = conductance
B_e = susceptance

$$\varepsilon' = \frac{G_e + \left(\frac{\lambda g}{2a}\right)^2}{1 + \left(\frac{\lambda g}{2a}\right)^2} \quad (15)$$

$$\varepsilon'' = \frac{-B_e}{1 + \left(\frac{\lambda g}{2a}\right)^2} \quad (16)$$

$$\epsilon_r = \varepsilon' - j\varepsilon'' \quad (17)$$

Where,
ε' = storage factor
ε'' = loss factor
ϵ_r = dielectric constant

PROCEDURE AND PRECAUTIONS
Different physical states of weighed samples (i.e., Rice, Wheat, Red Split Gram, Green Gram, and Bengal Gram) for measurements are taken into the sample holder, and try to make it homogeneous so that no air gap is present in it.

Now, the sample holder is carefully tightened with the help of nuts and screws to the slotted section of the rectangular waveguide of respective operating frequencies, and it is vertically aligned. After that, apply the Gunn Power supply to the Gunn oscillator and determine the two voltage minima shifts with the help of the SWR meter and slotted section;

determine the guided wavelength 'λ_g' and then VSWR with the help of related formulas and equations, and then determine the dielectric constant with the help of computer programs.

Some important precautions regarding the experimental setup and procedure have to be kept in mind as follows:

- The weight of each sample must be read out before inserting it in the sample holder or before starting the measurements for every state of the sample.
- The sample holder must be dried properly to avoid losses due to moisture content in the dry or saturation state of the cereal.
- For the measurement of moisture content in decreasing order, we need sun illumination to reduce the moisture content of the saturated sample; thus, the measurements should be completed in a day.

For the respective saturated sample to get proper sunlight and to prevent unnecessary moisture changes due to varying environmental conditions at night.

- The radiation losses are caused by to inhomogeneous surface of the sample filled in the sample holder. It should be ensured that the surface of the cereal is as homogeneous as possible.
- Store the grain sample in the container after the measurement for each of the three states properly to avoid the original mass material loss of the sample.
- Due to improper procedure, lack of fundamentals about the microwave equipment and components, and shortcomings in the proper arrangement of the sample in the sample holder may lead to variations in the measurements of dielectric constant and loss factor of grains under test.

RESULTS AND DISCUSSIONS
For frequencies 5.30 GHz and 6.60 GHz, measurements taken for different form of cereals, which includes dielectric constant and loss factor (i.e., ε' and ε''), are given as follows.

TABLE 3: Dielectric properties of grains under different conditions.

Samples	Dielectric Properties	
	Dielectric Constant	Loss Factor
Preliminary		
Wheat	9.0370	0.5077
Rice	8.7754	1.0614
Arhar	8.6727	0.0591
Chana	8.4098	0.8460
Moong	8.8048	1.2907
Oven Dried		
Wheat	8.8458	0.8423
Rice	8.2015	0.2351
Arhar	8.1903	1.5508
Chana	8.0805	1.6259
Moong	8.4429	0.5021

Samples	Dielectric Properties	
	Dielectric Constant	**Loss Factor**
Saturated		
Wheat	11.0423	3.9736
Rice	11.0012	3.2430
Arhar	10.8084	2.3152
Chana	11.2015	3.5625
Moong	10.7458	2.6927

A. A combined study of Cereals and Pulses In order to determine the variability of dielectric constant with frequency, the measurements were made at different frequencies. The values of the dielectric constant are calculated for different samples for preliminary, oven-dried, and saturated states, respectively, in the frequency range 5.30 GHz to 6.60 GHz. It is observed that the dielectric constant of five samples is different due to the difference in their physical properties and the presence of moisture content. The data have been obtained by taking ten sets of readings for each sample, and each set comprises three values of the shift in minima obtained throughout the length of the slotted waveguide. In all, thirty readings were taken for each sample for each frequency. The process is repeated in order to check the accuracy and precision of the microwave system used. The sets of readings were taken for the frequency mentioned in Table 1, Table 2, and Table 3 can also be predicted that there is a slight variation in the value of the dielectric constant with the increase in frequency.

B. Resultant Variation in Dielectric Constant with different moisture content, the variability in dielectric constant and loss factor can be attributed to the presence of moisture in the samples, which they absorb when kept exposed to the atmosphere at different microwave frequencies.

TABLE 4: Dielectric constant for 30% moisture content.

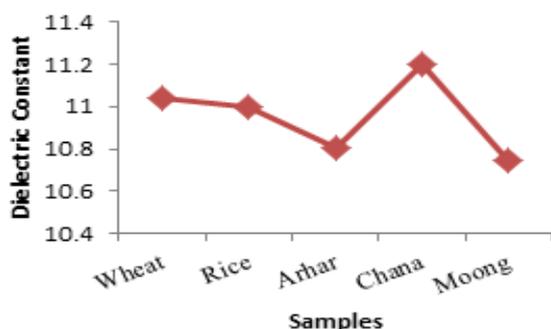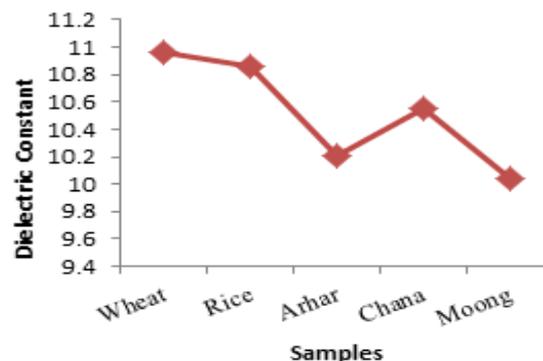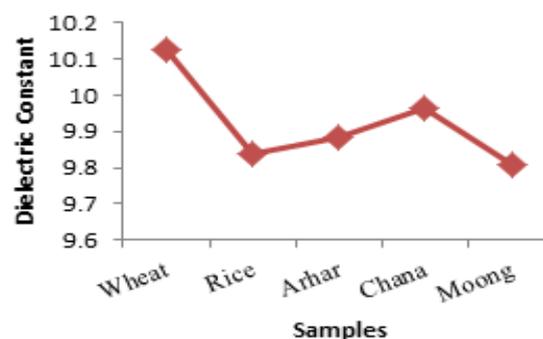| Samples	Dielectric Constant (5.3 GHz)
Wheat	11.0423
Rice	11.0012
Arhar	10.8084
Chana	11.2015
Moong	10.7458

FIGURE 5: Variation in dielectric constant of cereals and pulses having 30% moisture.

TABLE 5: Dielectric constant for 20% moisture content.

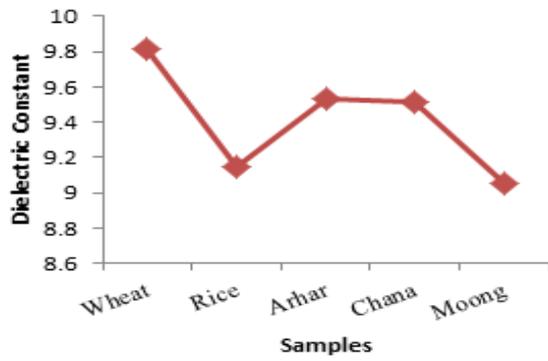| Samples	Dielectric Constant (5.3 GHz)
Wheat	10.9652
Rice	10.8620
Arhar	10.2102
Chana	10.5520
Moong	10.0462

FIGURE 6: Variation in dielectric constant of cereals and pulses having 20% moisture.

TABLE 6: Dielectric constant for 10% moisture content.

Samples	Dielectric Constant (5.3 GHz)
Wheat	10.1261
Rice	9.8401
Arhar	9.8815
Chana	9.9625
Moong	9.8091

FIGURE 7: Variation in dielectric constant of cereals and pulses having 10% moisture.

TABLE 7: Dielectric constant for 5% moisture content.

Samples	Dielectric Constant (5.3 GHz)
Wheat	9.8105
Rice	9.1456
Arhar	9.5325
Chana	9.5119
Moong	9.0552

FIGURE 8: Variation in dielectric constant of cereals and pulses having 5% moisture.

TABLE 8: Dielectric constant for 2% moisture content.

Samples	Dielectric Constant (5.3 GHz)
Wheat	9.0255
Rice	8.9112
Arhar	9.0856
Chana	8.9456
Moong	8.9196
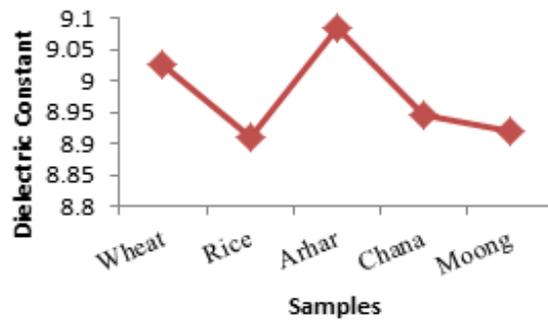
FIGURE 9: Variation in dielectric constant of cereals and pulses having 2% moisture.

TABLE 9: Loss factor for 30% moisture content.

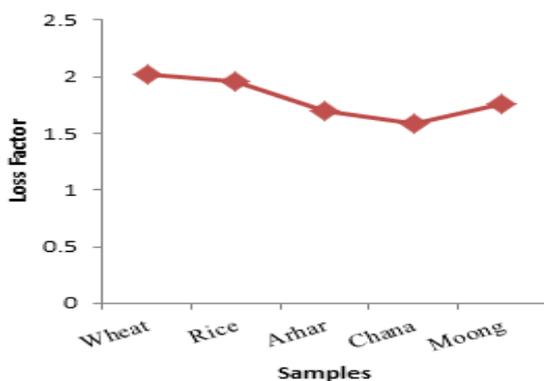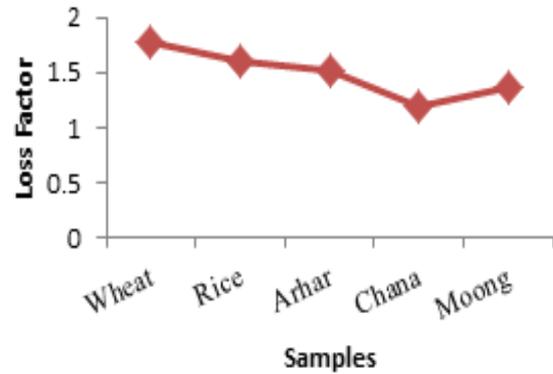| Samples	Loss Factor (at 5.3 GHz)
Wheat	2.0152
Rice	1.9573
Arhar	1.6955
Chana	1.5868
Moong	1.7532

FIGURE 10: Variation in loss factor of cereals and pulses having 30% moisture.

TABLE 10: Loss factor for 20% moisture content.

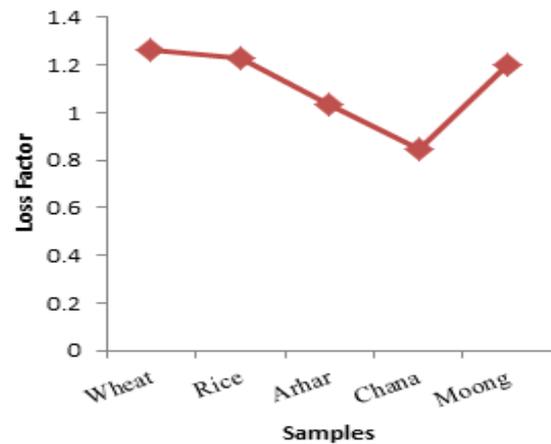| Samples	Loss Factor (at 5.3 GHz)
Wheat	1.7851
Rice	1.6123
Arhar	1.5103
Chana	1.1961
Moong	1.3577

FIGURE 11: Variation in loss factor of cereals and pulses having 20% moisture.

TABLE 11: Loss factor for 10% moisture content.

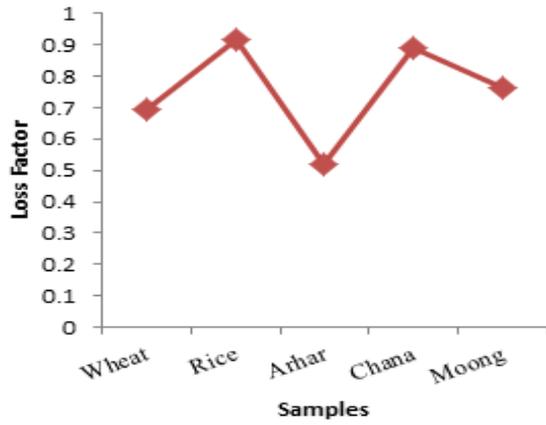| Samples	Loss Factor (at 5.3 GHz)
Wheat	1.2613
Rice	1.2305
Arhar	1.0325
Chana	0.8462
Moong	1.1985

FIGURE 12: variation in loss factor of cereals and pulses having 10% moisture.

TABLE 12: Loss factor for 5% moisture content.

Samples	Loss Factor (at 5.3 GHz)
Wheat	0.6933
Rice	0.9156
Arhar	0.5213
Chana	0.8923
Moong	0.7658

FIGURE 13: Variation in loss factor of cereals and pulses having 5% moisture.

TABLE 13: Loss factor for 2% moisture content.

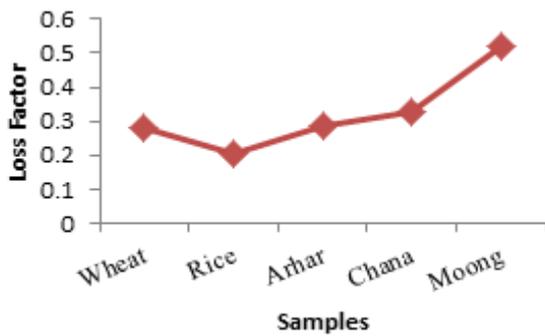| Samples	Loss Factor (at 5.3 GHz)
Wheat	0.2832
Rice	0.2059
Arhar	0.2856
Chana	0.3251
Moong	0.5194

FIGURE 14: Variation in loss factor of cereals and pulses having 2% moisture.

TABLE 14: Tabulated form of dielectric constant and loss factor of grains of CJ-band (6.6 GHz).

Samples	Dielectric Constant	Loss Factor
Preliminary		
Wheat	8.8451	0.4132
Rice	8.5023	0.6594
Arhar	8.4805	1.2361
Chana	8.2315	0.1625
Moong	8.5509	1.2365
Oven Dried		
Wheat	8.6450	0.1527
Rice	8.0509	1.6718
Arhar	8.0010	0.9827
Chana	7.9998	1.1560
Moong	8.0521	0.2376
Saturated		
Wheat	10.8264	3.7927
Rice	10.7765	3.1592
Arhar	10.2128	2.6051
Chana	11.0519	3.0519
Moong	10.5023	2.0010

TABLE 15: Dielectric constant for 30% moisture content.

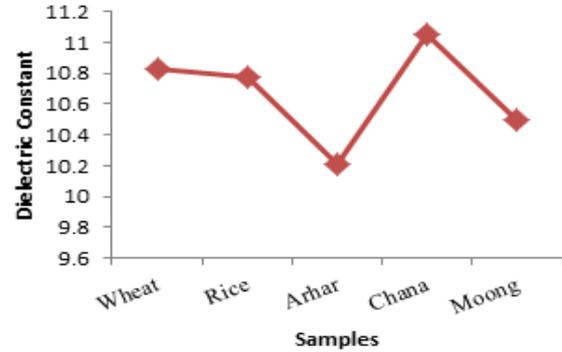| Samples	Dielectric Constant (6.6 GHz)
Wheat	10.8264
Rice	10.7765
Arhar	10.2128
Chana	11.0519
Moong	10.5023

FIGURE 15: Variation in dielectric constant of cereals and pulses having 30% moisture.

TABLE 16: Dielectric constant for 20% moisture content.

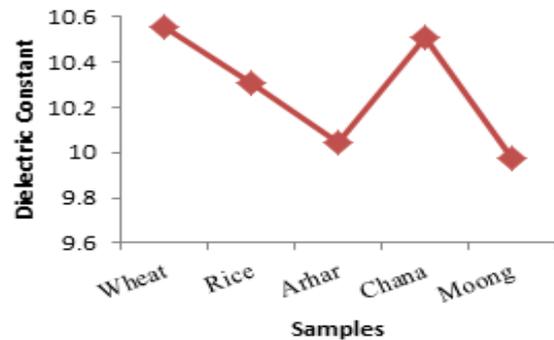| Sample	Dielectric Constant (6.6 GHz)
Wheat	10.5537
Rice	10.3096
Arhar	10.044
Chana	10.5118
Moong	9.9745

FIGURE 16: Variation in dielectric constant of cereals and pulses having 20% moisture.

TABLE 17: Dielectric constant for 10% moisture content.

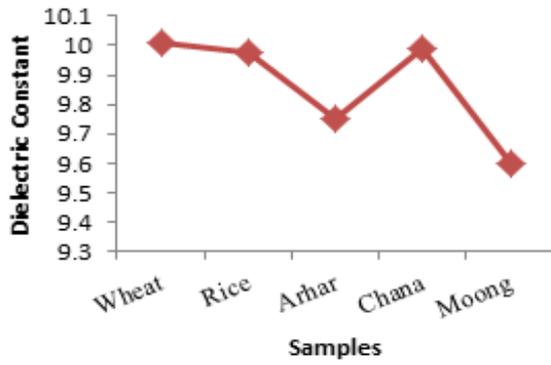| Sample	Dielectric Constant (6.6 GHz)
Wheat	10.0115
Rice	9.9737
Arhar	9.7513
Chana	9.988
Moong	9.5967

FIGURE 17: Variation in dielectric constant of cereals and pulses having 10% moisture.

TABLE 18: Dielectric constant for 5% moisture content.

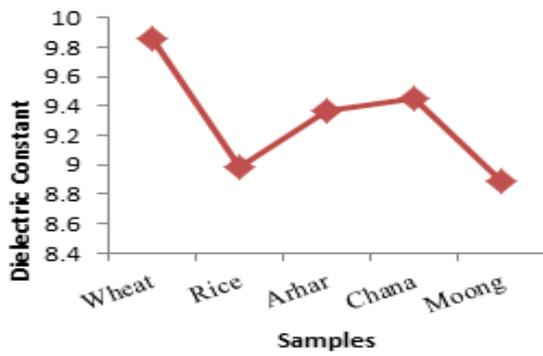| Samples	Dielectric Constant (6.6 GHz)
Wheat	9.862
Rice	8.9872
Arhar	9.3705
Chana	9.4492
Moong	8.8903

FIGURE 18: Variation in dielectric constant of cereals and pulses having 5% moisture.

TABLE 19: Dielectric constant for 2% moisture content.

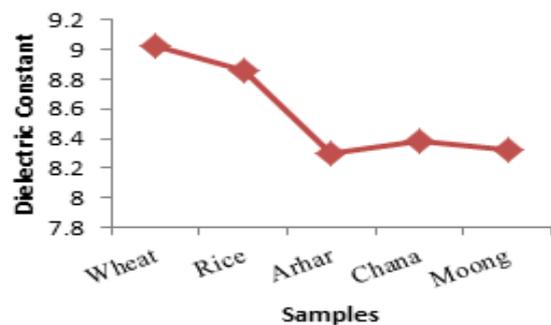| Samples	Dielectric Constant (6.6 GHz)
Wheat	9.0255
Rice	8.8562
Arhar	8.2975
Chana	8.3864
Moong	8.3203

FIGURE 19: Variation in dielectric constant of cereals and pulses having 2% moisture.

TABLE 20: Loss factor for 30% moisture content.

Samples	Loss Factor (at 6.6 GHz)
Wheat	2.3702
Rice	2.3353
Arhar	1.8566
Chana	2.2803
Moong	2.0410

FIGURE 20: Variation in loss factor of cereals and pulses having 30% moisture.

TABLE 21: Loss factor for 20% moisture content.

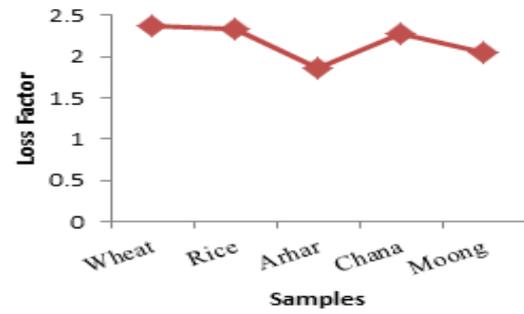| Samples	Loss Factor (at 6.6 GHz)
Wheat	1.9614
Rice	2.0115
Arhar	1.6679
Chana	2.0573
Moong	1.9764

FIGURE 21: Variation in loss factor of cereals and pulses having 20% moisture.

TABLE 22: Loss factor for 10% moisture content.

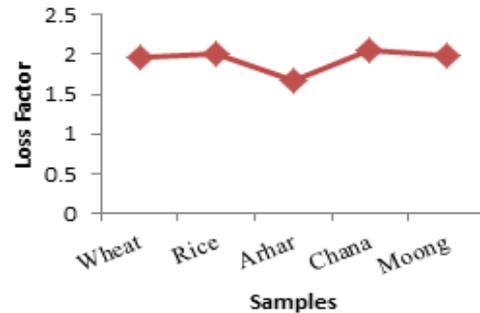| Samples	Loss Factor (at 6.6 GHz)
Wheat	1.4650
Rice	1.8644
Arhar	1.1213
Chana	1.8154
Moong	1.5028

FIGURE 22: Variation in loss factor of cereals and pulses having 10% moisture.

TABLE 23: Loss factor for 5% moisture content.

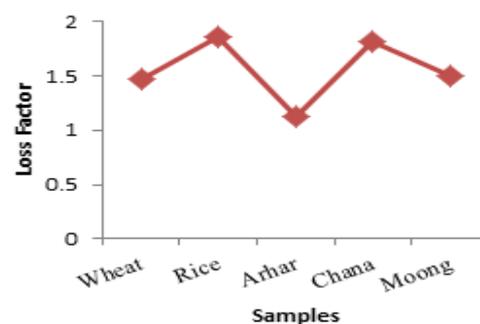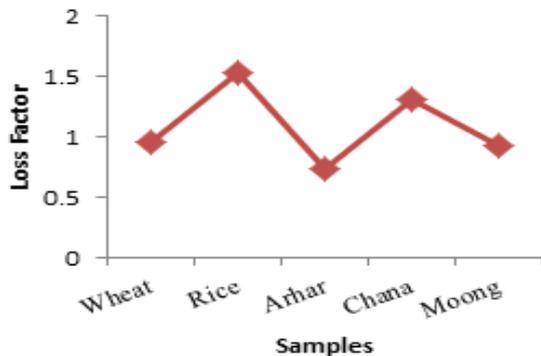| Samples	Loss Factor (at 6.6 GHz)
Wheat	0.9523
Rice	1.5319
Arhar	0.7428
Chana	1.3074
Moong	0.9308

FIGURE 23: Variation in loss factor of cereals and pulses having 5% moisture.

TABLE 24: Loss factor for 2% moisture content.

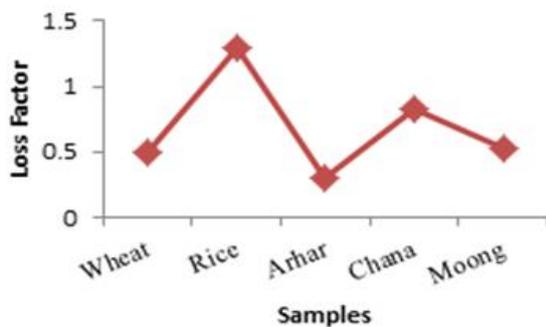| Samples	Loss Factor (at 6.6 GHz)
Wheat	0.5017
Rice	1.2886
Arhar	0.3012
Chana	0.8305
Moong	0.5298

FIGURE 24: Variation in loss factor of cereals and pulses having 2% moisture.

DISCUSSION

Through all these tables and figures, we observed that the value of ϵ' and ϵ'' increases with the increase in moisture content. This is due to the presence of free water molecules in the sample. The dielectric constant of water is 80 at around 1 GHz, and it decreases with an increase in frequency, and also the dielectric constant changes when impurities are present in the water. For moisture content, just add distilled water to the samples. The loss factor increases with an increase in frequency. The dielectric constant and loss factor of the samples were measured after determining the weight of the sample before the measurement. Some measurements were also made before the settlement and just after adding water to cereals at the saturated limit of the water-cereals mixture.

In the present study, the measurements were made for the preliminary samples, oven-dried samples, and samples having moisture content of 2%, 5%, 10%, 20%, 30%. The results of measurements of moisture content of 2% to 30.00% have been reported in this properly.

Dielectric constant and loss factor change with humidity or water with water content, so that special arrangements have to be made to hold humidity constant and to determine its value, or we can do it naturally just by drying it in air. Grain moisture content is expressed as a percentage of moisture based on wet weight (wet basis) or dry matter (dry basis). Wet-basis moisture content is generally used. Dry basis is used primarily in research.

$$Mw \text{ (wet basis)} = (w-d)/w*(100) \qquad (18)$$
$$Md \text{ (dry basis)} = (w-d)/d*(100) \qquad (19)$$

Where,
w = wet weight, d = dry weight, M = moisture content on a percent basis. A representative sample must be obtained to provide a useful moisture content evaluation. Also, the moisture content of the product must be maintained from the time the sample is obtained until the determination is made by storing it in a sealed container. The moisture content can be determined by an oven method, which is a direct method. The grain is weighed and dried, then weighed again according to standardized procedures. The moisture content is calculated using the moisture content equations. Most moisture meters measure the electrical properties of grain, which change with the moisture content. This is considered an indirect method and must be calibrated by a direct method. It is important to follow the moisture meter directions carefully to achieve an accurate moisture test. A moisture meter should be periodically checked to see if it is accurate. One method of checking the meter is to compare it to at least two other meters.

TABLE 25: Comparison of dielectric properties of wheat.

M (%)	5.30 GHz		6.60 GHz	
	F	F	F	F
30	11.0423	2.0152	10.8264	2.3702
20	10.9652	1.7851	10.5537	1.9614
10	10.1261	1.2613	10.0015	1.4650
5	9.8105	0.6933	9.8620	0.9523
2	9.0255	0.2832	9.0255	0.5017

TABLE 26: Comparison of dielectric properties of rice.

M (%)	5.30 GHz		6.60 GHz	
	F	F	F	F
30	11.0012	1.9573	10.7765	2.3353
20	10.8620	1.6123	10.3096	2.0115
10	9.8401	1.2305	9.9737	1.8644
5	9.1456	0.9156	8.9872	1.5319
2	8.9112	0.2059	8.8562	1.2886

TABLE 27: Comparison of dielectric properties of Arhar.

M (%)	5.30 GHz		6.60 GHz	
	F	F	F	F
30	10.8084	1.6955	10.2128	1.8566
20	10.2102	1.5103	10.0440	1.6679
10	9.8815	1.0325	9.7513	1.1213
5	9.5325	0.5213	9.3705	0.7428
2	9.0856	0.2856	8.2975	0.3012

TABLE 28: Comparison of dielectric properties of Chana.

M (%)	5.30 GHz		6.60 GHz	
	F	F	F	F
30	11.2015	1.5868	11.0519	2.2803
20	10.5520	1.1961	10.5118	2.0573
10	9.9625	0.8462	9.9880	1.8154
5	9.5119	0.8923	9.4492	1.3074
2	8.9456	0.3251	8.3864	0.8305

TABLE 29: Comparison of dielectric properties of Moong.

M (%)	5.30 GHz		6.60 GHz	
	F	F	F	F
30	10.7458	1.7532	10.5023	2.0410
20	10.0462	1.3577	9.9745	1.9764
10	9.8091	1.1985	9.5967	1.5028
5	9.0552	0.7658	8.8903	0.9308
2	8.9196	0.5194	8.3203	0.5298

CONCLUSION

This study successfully measured and analyzed the dielectric constant and loss factor of grains at CJ-band and X-band microwave frequencies using the two-point waveguide method. A strong correlation between moisture content and dielectric response was observed across all five grains. Notably, ϵ' and ϵ'' increased with higher moisture content, consistent with the known behavior of water molecules in dielectric media. These findings provide critical baseline data for engineers and researchers working in agricultural sensing, RF drying systems, and remote detection of biological materials. The results remain relevant in the context of emerging microwave sensing technologies, where accurate material characterization plays a vital role.

This report also shows the behavior of the dielectric constant of cereals and pulses (wheat, rice, Arhar, Chana, Moong) using the theoretical model of the two-point method (wave guide method).

The dielectric constant is dependent on frequency and stays constant only over relatively small portions of the frequency spectrum. But, the variation of ϵ' with frequency is sufficiently gradual that it can be considered to be constant over a fairly wide frequency band for most common microwave applications. The percentage variation in ϵ'' is almost always greater than that of ϵ', so that ϵ'' should be measured near the frequency or frequencies of interest. In some cases, ϵ' is affected by temperature, so that the temperature should be held constant. The ϵ' and ϵ'' are directly proportional to the moisture content present in the sample.

The method for the complex permittivity of cereals has been developed by maintaining relationships of theoretical and physical significance. The estimated permittivity and loss factors of rice, wheat, Moong dal, Chana dal, and Arhar dal with average accuracies of 5 % to 10 % over the frequency 12.80 GHz and moisture content range from 2 % to 30 %, wet basis.

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