Journal of AgriSearch, 8 (4): 370-375
An Open Access International Peer Reviewed Quarterly

ISSN : 2348-8808 (Print), 2348-8867 (Online)
https://doi.org/10.21921/jas.v8i04.7756

Dielectric Properties of Sorghum Seeds in the Radio Frequency Range

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ABSTRACT
The dielectric parameters of hygroscopic materials such as seeds and grains vary greatly when subjected to varying electric field. The values of dielectric parameters such as dielectric constant, dielectric loss factor and other related parameters along with dielectric relaxation spectrum has tremendous application in processing industries, as it helps in determine online and instantaneous moisture content of seed lots during harvesting, processing, handling and transportation and in controlled heating without quality damage. For these operations the effect of frequency moisture and temperature of the material over wide frequency range is required. This paper presents the dielectric properties of sorghum seed (*Sorghum bicolour*) over the radio frequency range of 0.50 kHz to 10 MHz, determined by Hewlett-Packard (HP-4194A) impedance/gain phase analyzer over the moisture range of 2.9% to 18.5 % with corresponding bulk density and temperature range of 0.812-0.760 gm/ cm^3 and 30-45^{o}C , respectively.

KEYWORDS
Dielectric properties, hygroscopic material, radio frequency, dielectric relaxation

ARTICLE INFO

Received on	:	22/09/2021
Accepted on	:	05/12/2021
Published online	:	31/12/2021

INTRODUCTION

Dielectric properties that describes the interaction of a material with an electric field are the dielectric constant $\varepsilon^{'}$ and the dielectric loss factor $\varepsilon^{''}$, the real and imaginary part of the relative complex permittivity ε^* , expressed as

$$\varepsilon^* = |\varepsilon^*|\, e^{-i\delta} = \varepsilon^{'} - j\varepsilon^{''}$$

where δ is the loss angle of the dielectric and expressed as

$$\delta = tan^{-1}\left(\varepsilon^{'}/\varepsilon^{''}\right)$$

The $\varepsilon^{'}$ is a measure of electromagnetic energy stored in material while $\varepsilon^{''}$ describes energy dissipation rate in the material (Gracia *et al*, 2001). The loss tangent is used as dissipative parameter. The ac conductivity of dielectric in siemens/m is given as $\sigma = \omega\varepsilon_0\varepsilon^{''} \times 10^{-12} f\ \varepsilon^{''}$
Where; angular frequency $\omega = 2\pi f$, f is in Hz. The dielectric properties dictate the behavior of the material when subjected to radio frequency or microwave for purpose of heating or drying the materials. The power dissipation per unit volume (W/m^3) in dielectric is given by $P = E^2\ \sigma = 55.63 f E^2\ \varepsilon^{''} \times 10^{-12}$, where E represents the rms electric field intensity.
The dielectric properties of hygroscopic biological material such as seed and grains are much dependent on moisture and the way the water is held in grain structure determines the degree of dependency. The dielectric properties of such materials also vary greatly with frequency of applied field. This variation over a wide range of frequency is called dispersion or Dielectric Relaxation Spectrum (DRS) and mechanism responsible for such dispersion is called 'relaxation'.
The much of interest in dielectric properties of a material is the frequency region where dispersion occurs. DRS have tremendous utilities and applications in agro-based processing industries. Values of dielectric parameters along with DRS analysis are used for real-time moisture determination of seed and grains lots during harvesting, processing, handling and transportation.
The conventional hot air disinfestation is a slow process and creates non-uniform temperature distribution across the material and therefore amages heat sensitive commodities Wang *et al* (2001), (Hansen, 1992; Tang *et al*, 2000) . A more promising way of heating commodities is by means of radio frequency (RF) or microwave to control the insects. Many researchers (Wang *et al* (2001) Wang *et al* (2002) , (Tang *et al*, 2000) proposed thermal treatments based on RF energy to replace chemical fumigations to control the codling moth, Cydia pomonella (L) (Lepidoptera: Tortricidae), and other insect pest in walnut (Juglans regia L.). Headlee and Burdette (1929) , Headlee and Burdette (1929) reported results for determining lethal exposures of honeybee in a 12 MHz radio frequency field. Nelson and Charity (1972) suggested that it would be possible to generate differential heating in rice weevil, Sitophilus Oryzae (L) in hard red winter wheat in the frequency range between 10 and 100 MHz. Radio frequency (RF) dielectric heating treatment provides moderate reduction in bacterial pathogens populations and also increase the germination through reduction in hard seed percentage (Nelson *et al*, 2002). Consistent increase in alfalfa seed germination through hard seed reduction was achieved by dielectric heating at the frequencies 5, 10, 39, 2450 MHz (Nelson and Wolf, 1964; Nelson and Charity, 1972)

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Nelson *et al* (1985) reported that some small seed legumes such as alfalfa, Medicago-Sativa L., red clover, Trifolium Pretense L, and arrow leaf clover, Triplium Vesieulosum Savi, responded well with substantial increase in normal seedling germination and corresponding reduction in hard seed content. The dielectric properties of agricultural product are also useful in sensing of degree of maturity during the harvest seasons (Nelson *et al* (1994) ; Nelson *et al* (1995) . The electrical conductivity measurement has been potential use in to predict germination potential, vigour and growth rate (Beighley and Hopper, 1981; Heslehurst, 1988) and physical mechanical damage of grain (Couto *et al*, 1998). Another application of dielectric properties of agricultural materials is the measuring of oil content. An oil content of sunflower seeds has been successfully measured using the dielectric properties (Hunt *et al*, 1952). Sun *et al* (1995) and Kent (1987) provided a good source of information on dielectric properties of selected foods and agricultural materials but more wide and extensive data are needed for proper designing of equipment. The necessary dielectric properties data for evaluation of potentially new applications can be obtained by careful measurements. Research on some products has produced models that estimate the dielectric properties reasonably well (Mudgett, 1995; Dutta *et al*, 1995; Nelson, 1987), but in general, the needed properties can only be determined accurately by direct measurement, under the specific condition important for applications.

Agriculture has been and will continue to be the major lifeline of Indian economy. The sorghum (Sorghum bicolour) grain is used primarily as human nutritious food in various forms such as unleavened bread or cooked like rice. Sorghum is also malted, popped and several local preparations are made. It utilized as cattle feed, poultry ration and other industrial purposes such alcohol distilleries and starch production. Therefore, precision farming and quality control of sorghum grains and seeds at the time of harvesting, transportation and storage are important. The quality control of the grains and seeds can be done by knowing the dielectric properties. Knowledge of dielectric properties over radio and microwave frequencies are useful for on line instantaneous determination of moisture content, selective heating for insect and diseases control, drying, and reduction of hard seed percentage to induce germination. All above needed information on dielectric values across wide range of radio to microwave frequency. This paper presents data of the dielectric properties of sorghum seed and its dependence on frequency, moisture content, and temperature measured over the frequency range of 0.5 kHz -10 MHz.

MATERIALS AND METHODS

The sorghum seeds (Sorghum bicolour) selected for study was NSSG-1899 (Haritha) verity .In order to investigate the correlation between moisture content and dielectric parameters samples of different moisture levels were required. Initial moisture content of each sample were determined by Asae-Standard (1999) by drying triplicate 10 g samples in forced air-oven at 130 ^{0}C for few hours till weight become constant. This method relies on weight loss and the moisture content M (in percent and wet basis).It was not possible to obtain seed /grain samples of desired moisture content; therefore, sample was to be conditioned either by adding moisture or by drying. For obtaining moisture level greater than the initial level, distilled water was added to samples in jars, which were sealed and stored at 4 ^{0}C for at least 72 hours (Agrwal, 1999). The jars were frequently agitated to facilitate uniform distribution of moisture in samples. For moisture level lower than the initial level, samples were dried in open air for several hours to reach the lower desired moisture content. Before each measurement samples were allowed to equilibrate to room temperature for few hours. Hewlett-Packard (HP-4194A) impedance/gain phase analyzer was used in in determining the dielectric properties. The instrument employs microprocessor controlled built in bridges and resonant circuits. The results of measurement were displayed on a CRO-type screen. The instrument basically measures resistance, capacitance, inductance and loss angle. This analyzer was equipped with a test fixture (16047D) and specially designed coaxial cylindrical sample holder. The coaxial sample holder was filled evenly and uniformly with grain/seed sample following consistent filling procedure so that the kernel could get natural course of adjustment and normal course of density leaving minimum air filled space in between. The sample holder was then placed inside the temperature-controlled chamber with suitable height adjustment. The capacitance and dissipation factor measurements were repeated at the temperatures namely 30^o, 35^o, 40^o and 45^{o}C. This formed the one set of measurement over a sample of grain/seed of given moisture content. After completion of measurement over the temperature range of interest, the grain/seed sample was poured out of the sample holder and weighed so that bulk density of samples could be determined. Sample holder filling and impedance measurements over the whole temperature range were replicated three times for each lot of grain of given moisture content. On high and low moisture samples which were not in equilibrium with ambient condition of laboratory, moisture determinations were made before and after each series of measurement to detect any change in moisture content. Changes during measurements were negligible in all the cases. Measurements were then replicated over different temperatures as described above. The two other properties namely the dielectric loss factor and the electrical conductivity were calculated using the formulae.

RESULTS AND DISCUSSION

Frequency dependence

The experimentally determined values of dielectric constant**,** dielectric loss factor of selected seed at different discrete frequencies between at different moisture levels and at normal densities over the temperature range of 30– 45 ^{0}C are reported in Table 1. Here the dielectric constant and loss tangent were taken as independent parameters and the dielectric loss factor and electrical conductivity were determined as a function of the dielectric constant and loss tangent. To illustrate the pattern of dependence of dielectric parameters on frequency curves are drawn for sorghum .The invention of density independent function, widely applicable for the different seeds and grains eliminated the need to analyze the density dependency. Therefore, in present investigation emphasis were given to study the frequency, moisture and temperature dependency at normal densities. While discussing the influences of factors other than temperature, discussion were confined to the data recorded at initial temperature, i.e. 30 ^{0}C. The dependence dielectric constant and dielectric loss factor were examined by plotting curves between dielectric constant and dielectric loss factor and the frequency at indicated moisture content and at 30^{0}C temperature for sorghum are shown in Fig. 1 and Fig. 2, respectively. From figure it is observed that both parts of the permittivity decreases with increase in frequency. These behaviors are likely due to relaxation mechanism operating at different frequencies. High values of dielectric constant at low frequency could be attributed to the electrode polarization and artifact of the instrument, whereas the high values of the dielectric loss factor may be attributed to electrode polarization, artifact of the instrument and increase in ionic or protonic conductivity (Magario and Yamaura, 1988). Comparison between the variations in dielectric constant and corresponding variation in dielectric loss factor with frequency showed that the changes in loss factor are less regular than the dielectric constant. Nelson (1979) reported similar behaviours in corn between the moisture range 10 to 50 percent and frequency range 1 to 11 GHz. In other study (Jones *et al*, 1978) on wheat and corn over the frequency range 1 to 200 MHz range similar behaviour were reported. The irregular behaviour of loss factor may be due to complex dielectric relaxation and dispersion phenomena.

Moisture dependence

Examining the data, reported in Tables 1 and 2 and Figures 1 and 2 the moisture dependence of both the parameters of effective permittivity at given frequency and temperature of sorghum revealed that both parts of the dielectric permittivity increases with increase of the moisture content at any given temperature and frequency. The rates of increase of both the parameters are high at low frequency which is obvious from the theory of relaxation mechanism. At low moisture content, particularly below 8% both parts of the permittivity are having small values. This could be due to the strong bound water state (monolayer) where distance between the water molecule and cell wall are very small and attraction force is very large. This large force prevents the water molecule to align in the field direction, and therefore the effective permittivity is small. As moisture content increases beyond 8%, increase in both the parts of the permittivity accelerates and this trend could be attributed to change of bound water state from first (monolayer) to second (multilayer) type. Sharp increase are noticed at all frequencies as the moisture content crossing over 13%.This behaviour could be ascribed to transition of bound water state from second (multilayer) to third (osmotic tension) type or free state water. At high moisture content the ionic or protonic conductivity is high therefore, at high moisture contents and low frequencies, the dielectric loss factors are considerably high. Because the density is an extensive property and therefore, the change in the effective permittivity results from the change in bulk density, since it is always translates in to change in the amount of water interacting with electric field.

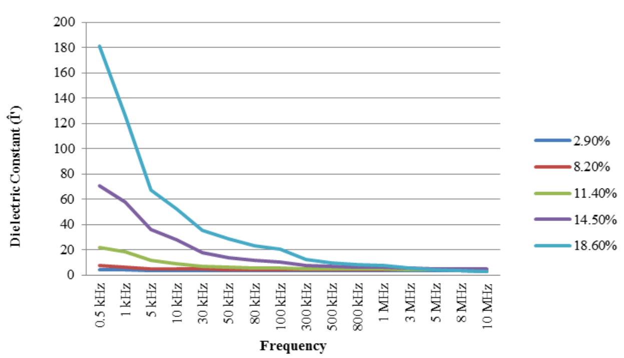

Fig. 1: Dielectric constant vs frequency curve of Sorghum Seed

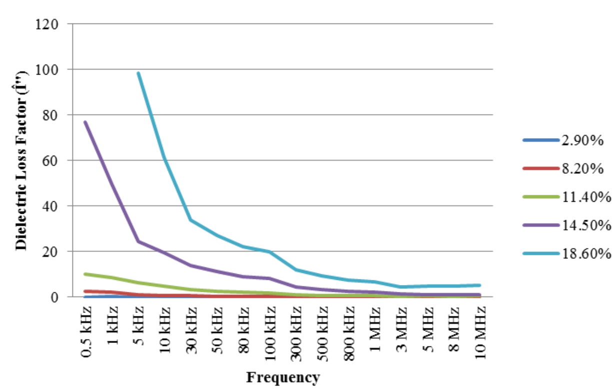

Fig. 2: Dielectric loss factor vs frequency curve of Sorghum seed

Temperature dependence

From Tables 1 and 2 it is observed that both the parts of the effective permittivity, the dielectric constant and dielectric loss factor of sorghum increased with increase in temperature at all moisture levels and frequencies in the temperature range 30-45 ^{0}C. At lower moisture levels the relationship between both parts of permittivity and the temperature are found to be linear at all frequencies, however a slight non-

Table 1: Dielectric properties of Sorghum at MC 2.90 & 8.20 % and BD:0.828 & 0.812 g m/ cm3

Freq (f)	MC: 2.90 %, BD: 0.828 gm/ cm^3								MC: 8.20 %, BD: 0.812 gm/ cm^3							
	Dielectric Constant (ε')				Dielectric Loss Factor (ε'')				Dielectric Constant (ε')				Dielectric Loss Factor (ε'')			
	30 °C	35°C	40°C	45°C	30°C	35°C	40°C	45°C	30°C	35°C	40°C	45°C	30°C	35°C	40°C	45°C
0.5 kHz	3.982	3.880	4.095	4.133	0.022	0.207	0.182	0.198	7.159	7.460	8.132	9.469	2.650	2.841	3.590	4.880
1 kHz	3.776	3.791	3.903	3.895	0.243	0.243	0.352	0.376	6.207	6.475	6.990	8.077	2.161	2.395	2.896	3.937
5 kHz	3.685	3.703	3.742	3.796	0.131	0.128	0.153	0.184	5.086	5.206	5.447	5.951	1.123	1.252	1.496	2.018
10 kHz	3.648	3.544	3.735	3.762	0.091	0.104	0.133	0.148	4.833	4.884	5.177	5.408	0.836	0.915	1.218	1.539
30 kHz	3.558	3.556	3.627	3.667	0.144	0.180	0.133	0.151	4.541	4.551	4.672	4.905	0.576	0.569	0.653	0.972
50 kHz	3.528	3.546	3.619	3.649	0.150	0.138	0.137	0.147	4.375	4.443	4.515	4.723	0.445	0.488	0.607	0.793
80 kHz	3.518	3.546	3.603	3.633	0.138	0.134	0.139	0.141	4.313	4.360	4.434	4.594	0.372	0.413	0.491	0.655
100 kHz	3.503	3.529	3.578	3.617	0.138	0.135	0.137	0.203	4.280	4.322	4.393	4.535	0.339	0.377	0.445	0.586
300 kHz	3.438	3.474	3.516	3.556	0.163	0.164	0.159	0.156	4.152	4.189	4.243	4.350	0.266	0.284	0.323	0.405
500 kHz	3.404	3.439	3.481	3.522	0.196	0.196	0.187	0.181	4.100	4.134	4.179	4.275	0.264	0.276	0.303	0.361
800 kHz	3.365	3.404	3.446	3.489	0.223	0.231	0.218	0.209	4.052	4.080	4.128	4.216	0.274	0.281	0.297	0.340
1 MHz	3.347	3.388	3.432	3.476	0.219	0.228	0.212	0.202	4.033	4.064	4.107	4.198	0.255	0.262	0.276	0.312
3 MHz	3.235	3.279	3.333	3.392	0.303	0.368	0.313	0.298	3.917	3.954	3.997	4.075	0.315	0.316	0.313	0.326
5 MHz	3.211	3.255	3.319	3.380	0.403	0.500	0.414	0.395	3.884	3.945	3.956	4.033	0.398	0.434	0.429	0.438
8 MHz	3.107	3.141	3.212	3.286	0.387	0.575	0.461	0.425	3.840	3.881	3.926	4.007	0.365	0.369	0.352	0.351
10 MHz	3.056	3.084	3.149	3.235	0.418	0.657	0.484	0.488	3.826	3.868	3.922	4.008	0.405	0.428	0.405	0.396

MC= Moisture Content; BD= Bulk Density

linearity is noticed at high moisture content and low frequencies, particularly at 5 kHz. In recent study on temperature dependence of dielectric properties of pecan, Lawrence *et al* (1992) reported similar variations in the temperature range 0-40 ^{0}C.

The effect of the temperature on the permittivity lies in the fact that temperature change modifies the energetic status of the molecules and their aptitude to rotate with electric field. As the temperature increases the molecular mobility increases and relaxation wavelength which is strongly related to the molecular mobility decreases (Barrow, 1988). Therefore, peaks of both parts of the permittivity shifts to higher frequency. Increase in temperature also increases the ionic conduction, leading to increase in dielectric loss factor. Thus both parts of the permittivity increases as temperature increases. At lower frequency and high moisture content ionic conduction as well as molecular mobility is more affected by the increase of temperature because of decrease of viscosity in osmotic or free water state. Therefore, under these conditions rate of increase of both parts of the permittivity with temperature are high and might be nonlinear.

The mean moisture coefficients for dielectric constant over the measured frequency range at given moisture range was varied from: 2.057-0.007; whereas for dielectric loss factor, it varies from 5.630-0.001. The magnitude of mean temperature coefficient was comparatively high at higher moisture content. This indicates that moisture has appreciable influence on mean temperature coefficient. In general it can be assumed that the mean temperature coefficients for dielectric constant are positive at all moisture content level and frequencies. These results are in agreement with the finding of Jones *et al* (1978), who reported positive temperature coefficients at radio frequencies for wheat, corn and soybean over temperature range 2-40 ^{0}C. Positive temperature coefficient was also reported for corn between the moisture range 10-19 percent

Table 2: Dielectric properties of Sorghum at MC 11.40 & 18.5 % and BD:0.789 & 0.760 gm/ cm ^{3}

Freq (f)	**MC: 11.40%, BD: 0.789 gm/ cm^3**								**MC: 18.5%, BD: 0.760 gm/ cm^3**							
	Dielectric Constant (ε')				Dielectric Loss Factor (ε'')				Dielectric Constant (ε')				Dielectric Loss Factor (ε'')			
	30 °C	35°C	40°C	45°C	30°C	35°C	40°C	45°C	30°C	35°C	40°C	45°C	30°C	35°C	40°C	45°C
0.5 kHz	21.634	24.827	29.679	36.965	10.084	12.700	17.340	26.466	181.010	212.415	276.30	334.00	649.499	747.69	1008.96	1240.97
1 kHz	18.247	20.684	24.521	30.459	8.661	10.649	13.906	19.762	126.342	144.535	188.23	218.517	355.799	410.184	571.589	691.23
5 kHz	11.603	12.828	15.023	18.473	6.397	7.493	9.317	12.379	66.829	74.157	87.904	97.682	98.556	116.641	152.938	183.010
10 kHz	8.797	10.071	11.652	14.133	5.029	6.092	7.587	9.952	52.523	57.892	67.523	74.031	61.467	71.668	92.287	109.127
30 kHz	6.899	7.271	8.063	9.469	3.316	3.912	4.972	6.773	35.437	39.912	45.488	50.317	33.824	39.238	47.858	55.828
50 kHz	6.142	6.463	7.063	8.044	2.617	3.025	3.891	5.221	28.727	32.432	36.924	41.082	27.039	30.866	36.925	42.438
80 kHz	5.711	5.956	6.406	7.092	2.070	2.401	3.040	4.077	23.075	26.339	30.132	33.524	22.183	25.053	29.657	33.749
100 kHz	5.532	5.749	6.144	6.737	1.853	2.146	2.699	3.615	20.684	23.721	27.149	30.266	20.158	22.736	26.808	30.438
300 kHz	4.931	5.066	5.305	5.644	1.105	1.273	1.597	2.097	12.071	14.137	16.085	17.929	12.123	13.839	16.341	18.567
500 kHz	4.786	4.846	5.033	5.296	0.897	1.017	1.259	1.629	9.623	11.249	12.626	13.956	9.360	10.536	12.499	14.268
800 kHz	4.603	4.689	4.844	5.057	0.717	0.812	0.994	1.275	8.012	9.371	10.329	11.275	7.414	8.079	9.629	11.907
1 MHz	4.549	4.629	4.769	4.960	0.679	0.757	0.919	1.164	7.410	8.687	9.489	10.286	6.687	7.107	8.483	9.745
3 MHz	4.323	4.387	4.487	4.622	0.548	0.585	0.674	0.813	5.248	6.613	6.940	7.301	4.706	3.820	4.536	5.273
5 MHz	4.252	4.310	4.396	4.513	0.625	0.642	0.716	0.818	4.380	6.102	6.364	6.613	4.715	2.950	3.452	4.060
8 MHz	4.208	4.265	4.348	4.456	0.549	0.552	0.604	0.681	3.327	5.773	4.896	6.122	4.989	2.319	4.131	3.136
10 MHz	4.199	4.261	4.339	4.445	0.611	0.602	0.646	0.716	2.767	5.688	5.730	5.979	5.440	2.159	2.734	2.904

MC= Moisture Content; BD= Bulk Density

at frequencies 20 MHz, 300 MHz and 2.45 MHz over the temperature range 25-60 ^{0}C (Nelson, 1979) . The mean temperature coefficients per unit moisture content of dielectric constant and dielectric loss factor for sorghum seed decreases with increase in frequency and the values of coefficients for dielectric constant over the frequency range 5 kHz-10 MHz varied from: 0.131-0.004; whereas for dielectric loss factor varies from 0.358-0.003. Variation in the mean temperature coefficient with per unit rise of the moisture content shows that the moisture content affects more than temperature.

CONCLUSION

The behavior of dielectric parameters and its values in radio frequency range of electromagnetic spectrum are useful in quality control of seeds and grains. The interpretation of permittivity variation and loss factor with moisture content could be useful in understanding the way the water held in the seeds and grains and this information is useful in optimization of storage condition of seeds and grains.

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Citation:
Rahman A, Shukla JP and Singh AK. 2021. Dielectric Properties of Sorghum Seeds in the Radio Frequency Range. *Journal of AgriSearch* **8**(4): 370-375