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Some Electrical Properties of Melon (*Citrullus colosynthis L*) Seeds

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Abstract

In this work, some electrical properties of melon (*Citrullus colosynthis L*), as a function of moisture content and frequency variations, were investigated using the parallel-plate capacitance technique. Results show that electrical resistance, conductivity, dielectric constant, loss factor, loss tangent and capacitance of melon seed were significantly affected by moisture and frequency variations in an alternating electric field. It was observed that electrical resistance decreased from 70.30 Ω to 16.53 Ω for corresponding moisture levels of 9.12% to 32.0% db. On the contrary, capacitance increased from 0.308 pF to 0.740 pF at 9.12% to 20.42% db moisture levels respectively and declined to 0.332 pF at 32.0% db moisture content. Dielectric constant and loss factor values both increased from 0.130 to 2.58 and 17.52 to 88.69 for corresponding increases in moisture from 9.12% to 32.0% db. Conversely, dielectric constant and loss factors values were observed to decrease with an increase in frequency values.

Keywords: Moisture content; Frequency; Loss factor; Electrical resistance; Conductivity

Introduction

Melon (*Citrullus Colosynthis L*), otherwise called Egusi in local parlance in Nigeria, is one of the most widely consumed and cultivated oil seeds in Africa. Its popularity and acceptability as a nutritionally and medically viable crop spans across all nations in Africa and even beyond. As specie of the Cucurbitaceae family, it is a vine crop that creeps on the ground and serves as a cover crop [1,2]. Approximately 120 days after planting, the ball-shaped fruit is harvested and allowed to undergo various unit operations. These include fermenting, washing off the tannins and drying. The proximate composition of melon seed is reported to be 45.95% of fat, 28% of crude protein, and 7.18% of fibre [3,4] and contains a good amount of sodium, calcium, magnesium, vitamins and iron [1]. This, perhaps, is the driving force for its use as a soup thickener when grounded or snack when roasted. Literature indicates that oil expressed from melon seeds contains reasonable quantities of unsaturated fatty acids, linoleic acids and triglycerides; thus, making it a potential source of biodiesel through transesterification [5-7].

However, melon seed deteriorates rapidly in value due to fungal infection during storage [8,3]. The negative effect of this is the change in colour, decrease in nutritional value and seed viability for planting [9]. Investigations further shows that moisture content plays a significant role in maintenance of seed quality in storage as reported by Nelson [10], that a 1% decrease in moisture can double the shelf life of melon seeds in storage.

Therefore, in order to reduce quality loss in stored melon seeds, clean and effective drying process must be conducted. Studies have shown that microwave heating is the cleanest, safest and most effective means of drying agricultural materials [10]. However, the application of microwave heating is precluded by studies on the electrical properties such as electrical resistance, capacitance, conductivity, dielectric loss factor and dielectric constant of that given biomaterial. This has motivated scientist and agricultural engineers to study the electrical properties of various agricultural materials based on their dependence on moisture content and frequency changes. However, there is no information or data on the electrical properties of melon seeds for effective microwave heating processes. It is therefore the objective of this paper to evaluate the effects of moisture content and frequency variations on the electrical resistance, conductivity, capacitance, dielectric constant and loss factor of melon seed.

Materials and Methods

Sample preparations

Melon seeds were obtained from the Swali market in Yenagoa, Bayelsa State, Nigeria in 2012 for the study. The sample seeds were processed and all unwanted materials removed before experimentation. The initial moisture content was determined by Oven drying method at 70 ± 5°C for 8 hours as recommended by ASAE standard (S368.4, 2000). Readings of the initial moisture content was replicated ten times and the average recorded as 12.01% dry basis.

To determine the effect of moisture content on the electrical properties of melon seeds, test samples were conditioned to desired moisture levels of 9.1,12.30,16.20,20.42,28.13 and 32.0% dry basis by adding calculated amounts of distilled water using the rewetting equation(1).

$$W_w = W_t\left(\frac{M_f - M_i}{100 - M_f}\right) \quad (1)$$

Where,

W_w=mass of water added g;

W_t=total mass of seeds g;

M_i=initial moisture content%;

M_f=final moisture content required%

The conditioned samples were stored in tightly sealed plastic bags at 5°C for 6 days to permit proper moisture distribution and, during

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testing; desired quantities of seeds were withdrawn from the respective bags and allowed to equilibrate to room temperature for 2 hours before use.

Apparatus used

The equipment used for this experiment as shown in Figure 1 is based on the capacitance technique and composed of an Aditeg function generator (FG 8030), a Matrix Oscilloscope (MOS-620CH), a Fluke Industrial Tru-Rms Multimeter (Seris 87V), a Camry Digital scale (EK 5350), Digital Caliper and a modified Wheatstone bridge circuit. The Aditeg function generator was used to produce an alternating current with variable magnitude and frequency, while the Matrix Oscilloscope displayed the attendant sinusoidal waveform. The Fluke industrial Multimeter was used to measure the resistance and capacitance of both the variable resistors and samples, whereas the modified Wheatstone bridge circuit and the mathematical eqns (1-5) used are as follows:

Dielectric constant, ε^1

$$\varepsilon^1 = \frac{1}{2\pi f \varepsilon_0} \times \frac{L}{A} \times \frac{x_s}{R_s^2 + x_s^2} \quad \text{.......................} \quad (2)$$

Dielectric loss factor, ε^{11}

$$\varepsilon^{11} = \frac{1}{2\pi f \varepsilon_0} \times \frac{L}{A} \times \frac{R_s}{R_s^2 + x_s^2} \quad \text{.............................} \quad (3)$$

Where,

L=separation distance between sample holders, cm

A=crossectional area of sample holder, cm^2

R_S=resistance of sample, Ω

$x_s = \frac{1}{2\pi f C_s}$ =capacitive reactance of the sample

C_S=capacitance of the sample, $p_F=C_2(R_1/R_3)$

Loss tangent, δ

$$\tan\delta = \frac{\varepsilon^{11}}{\varepsilon^1} \quad \text{.......................} \quad (4)$$

Effective conductivity, σ

$$\sigma = \omega\varepsilon_0\varepsilon^{11}\left(\frac{s}{m}\right) \quad \text{.....................} \quad (5)$$

Where,

f=measuring frequency, Hz

ε_0=permittivity of free space (8.85×10^{-12} f/m)

Procedure

The experimental setup is as shown in Figure 1 above and using the Camry digital balance, a sample weighing 150 g was drawn from each of the predetermined moisture levels and placed in the sample holder for test. In order to attain a consistent normal force which improved contact between the sample and holder, a mass of 4 kg was placed on the platform of the test stand. The function generator was then set to the desired frequency level of 1 KHz and the alternating current (ac) sine wave output adjusted until amplitude of 2 volts was obtained. At this amplitude, the sine wave form was stable and move readable.

Measurements were then made of the distance separating the two aluminium plates in the test stand. The bridge circuit was then balanced by adjusting R_1 and R_2 until the peak amplitudes of the two sine waves occur at the same ordinate value. The function generator was then disconnected from the circuit and resistance measurements of R_1, R_2 and R_3 were taken. Capacitor, C_2 was then disconnected and its capacitance measured. Three replications were made and the average recorded and used to calculate the desired parameters.

For the effect of frequency variations, four frequency levels of 1 KHz, 10 KHz, 100 KHz and 1 MHz were selected and investigated at a moisture level of 16.12% db. A sample of 150 g was drawn and placed in the test cell and the above test procedures repeated at the desired frequency levels. The entire experiment was conducted at the Food Process Engineering Laboratory of the Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria.

Results and Discussions

A summary of the effect of moisture content on the electrical properties of Melon seed is presented in Table 1 below:

Effect of moisture on electrical resistance, R_s

As indicated in Table 1 above, electrical resistance which is the opposition to flow of current, generally, has a negative trend with moisture increase in melon seed. At a moisture level of 9.12% db, a resistance of 70.30 Ω was obtained. The resistance value then decreased to 16.53 Ω at a moisture level of 32.0% db. This implies that, at lower moisture levels, fewer electrons are free to flow. However, at higher moisture level, mobility of polarized water molecules in the melon seed increased, thus facilitating better current carrying capability. These findings are in good agreement with that of Mahmoud and Reza [11]. The negative relationship between electrical resistance and moisture content is represented by Figure 2 below.

Effect of moisture content on capacitance, C_s

Capacitance is defined as the ability of a material to store electric charge. As shown in Table 1 capacitance of melon seed generally increased from 0.308 pF to 0.740 pF at 9.12% db and 20.42% db moisture levels respectively. The capacitance value then decreased to

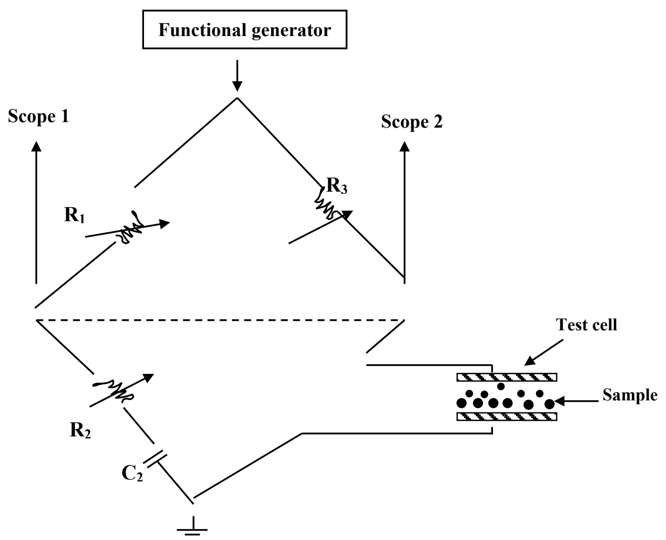

Figure 1: A modified Wheatstone bridge circuit.

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MC (%)	Plate Sep. (cm)	Plate area (cm^2)	R_1 (Ω)	R_2 (Ω)	R_3(Ω)	C_2(pF)	R_S(Ω)	C_S (pF)	X_S (Ω)	ε'	ε''	Tan δ	Σ (s/m)
9.12	1.38	24.53	42.30	80.50	36.94	269	70.30	0.308	0.00052	0.130	17.517	156.74	97.4
12.30	1.44	24.53	73.10	26.22	36.94	273	43.25	0.540	0.00029	0.174	36.651	150.62	203.8
16.20	1.49	24.53	95.20	81.10	36.94	278	31.47	0.716	0.00022	0.292	41.694	142.81	231.9
20.42	1.50	24.53	98.80	67.20	36.94	277	25.13	0.740	0.00022	0.383	43.754	114.23	243.3
28.13	1.53	24.53	46.63	32.68	36.94	273	22.08	0.345	0.00046	0.997	54.665	54.82	304.0
32.0	1.64	24.53	45.56	20.39	36.94	269	16.53	0.332	0.00048	2.58	88.691	34.38	493.2

Table 1: Effect of moisture on electrical properties of Melon seed.

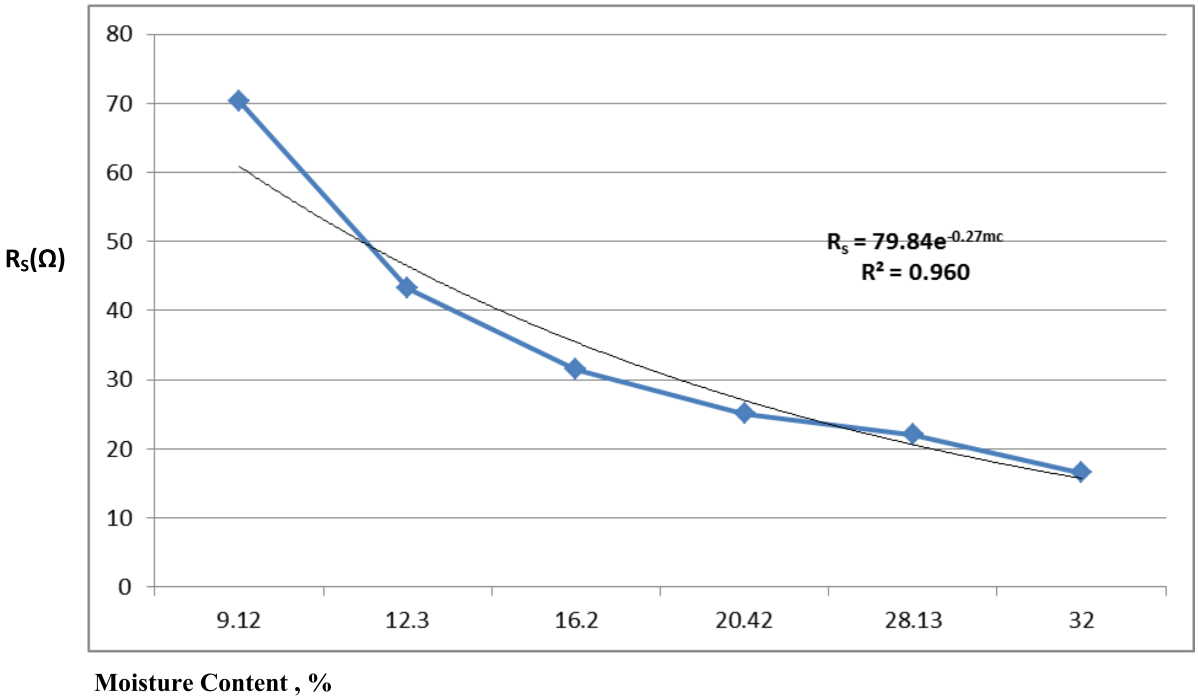

Figure 2: Effect of moisture on electrical resistance of melon seed.

0.332 pF at a moisture level of 32.0% db. This means that the charge storing capability of melon seed drops as moisture content is raised beyond 20.42% db. However, the relationship between moisture content and capacitance of melon seed is presented in Figure 3.

Effect of moisture content on dielectric constant, ε^1

Data presented in Table 1 shows a positive correlation between moisture content and dielectric constant. At 9.12% db moisture level, a corresponding dielectric constant of 0.13 was recorded. The dielectric constant value then increased steadily to 2.58 at 32.0% db moisture level. Dialectic constant, ε' of a material which is the ratio of its capacitance to the capacitance of air under the conditions being studied, is a vital variable in microwave heating. Thus, the steady rise in dielectric constant as a function of moisture in melon seed is an indication that melon seed is capable of storing a greater quantity of electromagnetic energy. This could be attributed principally to the more polarization of water and ionization of bound salts associated with the mobility of water molecules in the seed. The findings here are in concord with that of Burubai and Sipahioghi [12,13]. The correlation between moisture level and dielectric constant is shown in Figure 4.

Effect of moisture content on dielectric loss factor, ε^{11}

The behavior of dielectric loss factor as a function of moisture is aptly depicted in Table 1. Data reveals that dielectric loss factor of melon seed is highly influenced by moisture changes. At 9.12% db moisture level, a dielectric loss factor of 17.52 was obtained. This value increased sharply to 88.69 at a corresponding moisture level of 32.0% db moisture level. The dielectric loss factor is a measure of the amount of energy that the material will dissipate when subjected to an alternating electric field. Therefore, the positive relationship between moisture and dielectric loss factor is a good one for microwave heating and could be attributed to dipolar relaxation and ionic conduction. This is because water is dipolar in nature and its molecules try to follow the electric fields as they alternate at the set frequency. The rotations of the water molecules produce the heat. Therefore, at higher moisture levels, more water molecules are liberated to undertake this rotation; thus, increasing the dielectric loss factor. Similar results were obtained by Kamil and Burubai [14,12]. Figure 5 shows the graphical and mathematical relationship between the two variables.

Effect of moisture on loss tangent, σ

Agricultural materials and food products tend to behave like resistors and capacitors when introduced into an electric circuit. However, in an ideal circuit, the magnitude of current will always lead the voltage by 90°. But this loss angle is called the loss tangent, σ. The dependence of loss tangent on moisture variation is shown in Table

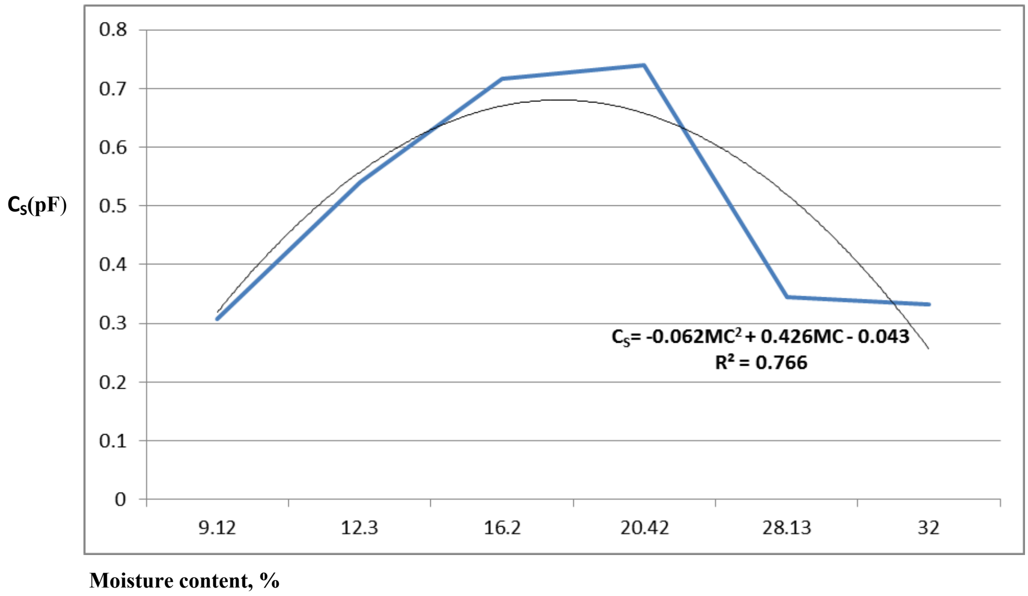

Figure 3: Effect of moisture on capacitance of melon seed.

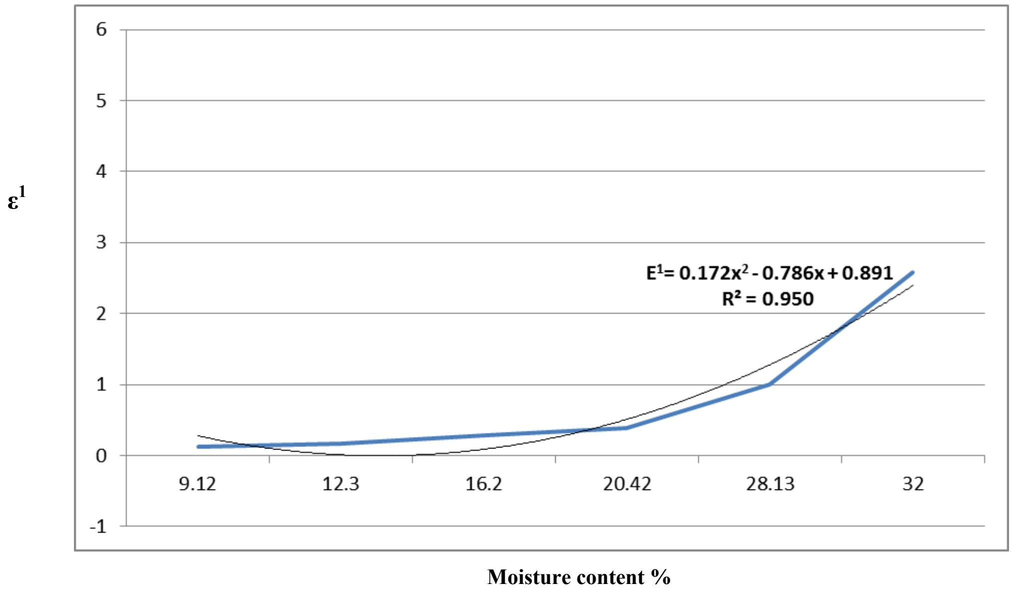

Figure 4: Effect of moisture on dielectric constant of melon seed.

1. Results show that loss tangent decreases as moisture increases. At 9.12% db moisture level, a loss tangent value 156.74 was noted and at 32.0% db moisture level, a corresponding loss tangent value of 34.38 was recorded. This steady decrease in loss tangent reveals that at higher moisture content, less energy is given out by the melon seed. These results agree with that of Afzal [15]. The mathematical relationship between loss tangent and moisture content is represented in Figure 6.

Effects of moisture on effective electrical conductivity, σ

In general, effective electrical conductivity of melon seed in response to moisture variations exhibited a linear increase. At 9.12% db and 32.0% db moisture levels, effective electrical conductivities of 97.4×10^{-8} s/m and 493.2×10^{-8} s/m were respectively observed. This property is a good indication that Ohmic heating and pulse electric field processing technologies can be applied to melon seed even during storage to cause microbial inactivation. The attendant increase in electrical conductivity can be attributed to ionic conduction as increase in moisture content generally introduces more water molecules into the flow path of mobile electrons. These results agree with that of Castro [16]. The mathematical and graphical dependence of the two parameters is given in Figure 7 below.

Effect of frequency variations on electrical resistance and capacitance

The influence of frequency changes on the free flow of current on melon seed is shown in Table 2. It is clear that resistance increased

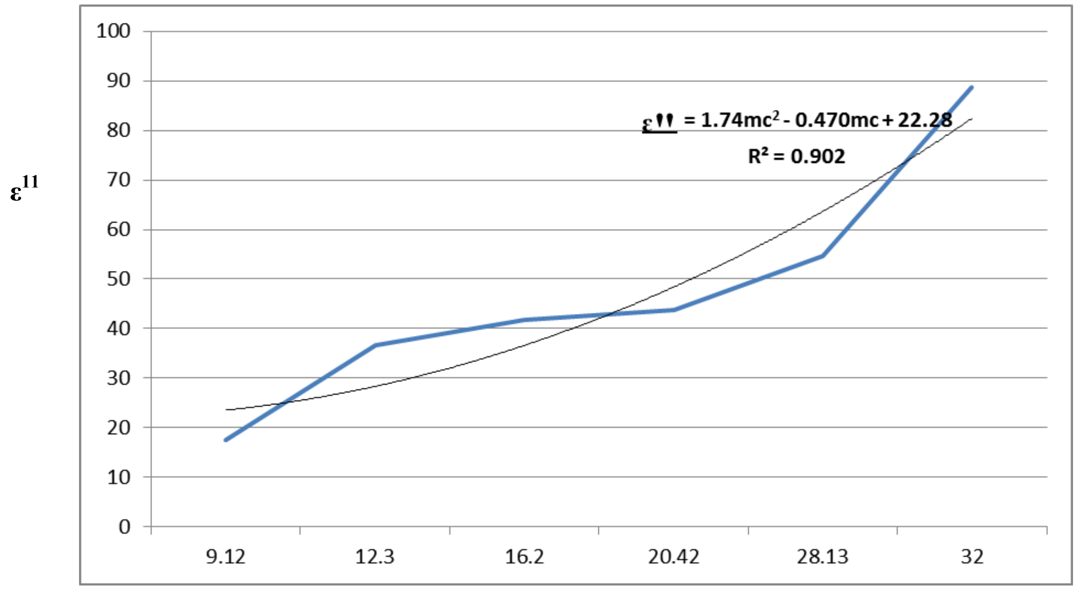

Figure 5: Effect of moisture on dielectric loss factor of melon seed.

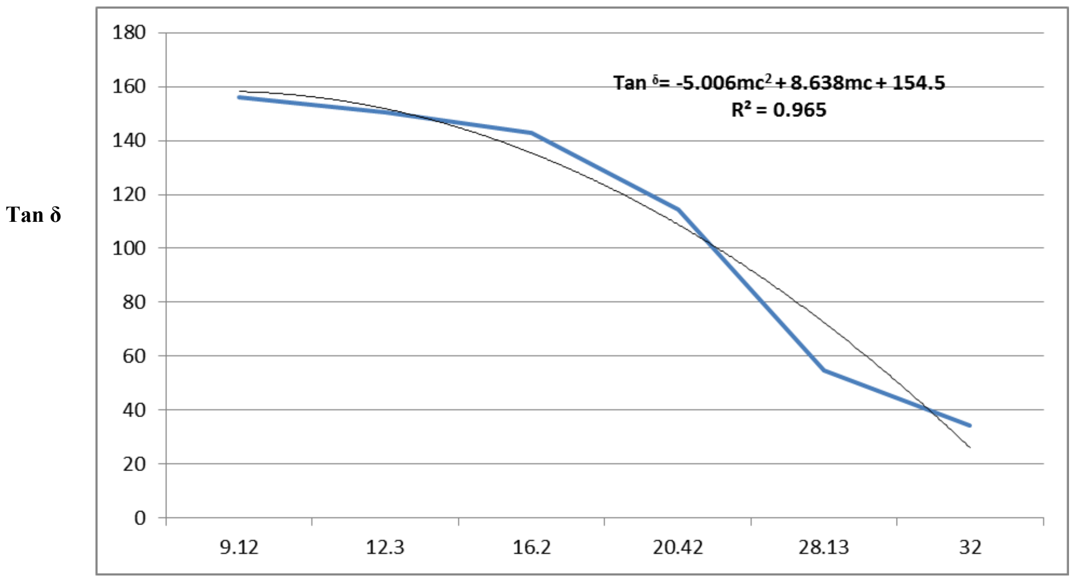

Figure 6: Effect of moisture on loss Tangent of melon seed.

from 17.07 Ω to 23.46 Ω at frequency levels of 1 KHz and 100 KHz respectively. Resistance value then jumped to 30.04 Ω at 1 MHz. This property is important because, when microwave energy is incident on a food material, part of the energy is absorbed by the food, leading to its temperature rise (due to increase in resistance). Results obtained here agree with that of Mahmoud and Reza [11] on black-eyed pea. The correlation between electrical resistance and frequency variation is given in Figure 8.

Furthermore, as revealed in Table 2, the capacitance of melon seed has a negative trend with frequency increase. At a frequency of 1 KHz, a capacitance of 0.509 pF was recorded. This capacitance value steadily declined to 0.232 pF at 1 MHz. Similar results are reported by Mahmoud and Reza [11] for black-eyed pea. Therefore, the relationship between both resistance and capacitance of melon seed and frequency variations is presented in Figure 8.

Effect of frequency variations on dielectric constant, ε' and loss factor ε''

The influence of frequency variations on the dielectric constant of melon seed is reported in Table 2. Results show that generally dielectric constant decreased with increase in frequency of oscillations.

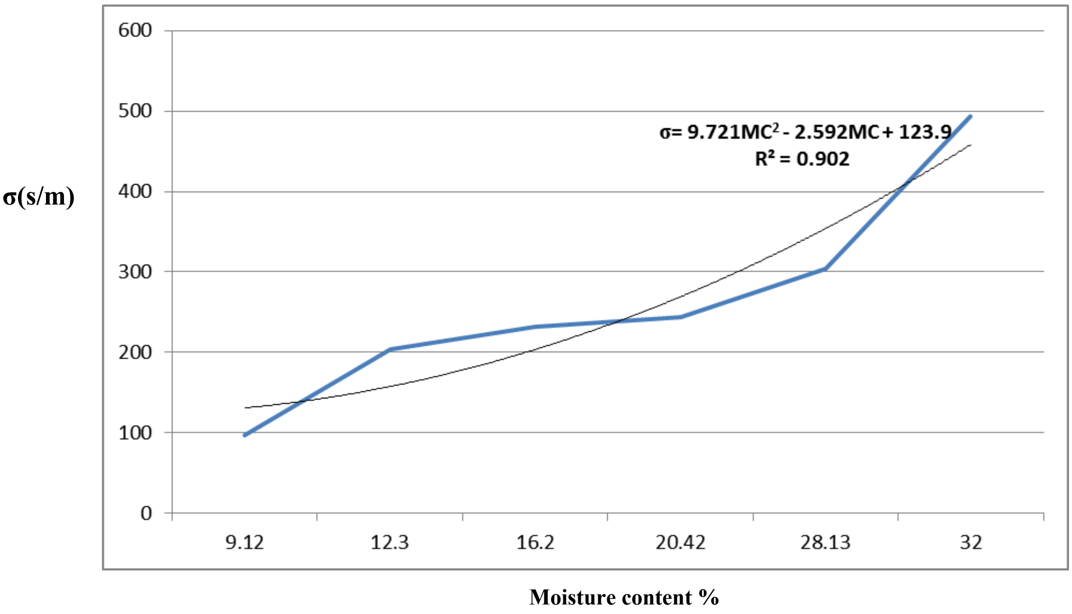

Figure 7: Effect of moisture on electrical conductivity of melon seed.

Frequency	Plate Sep. (cm)	Plate area (cm²)	R_1 (Ω)	R_2 (Ω)	R_3 (Ω)	C_2(pF)	R_s (Ω)	C_s (pF)	X_s (Ω)	ε'	ε''
1 KHz	1.68	24.53	48.63	32.30	25.70	269	17.07	0.509	0.3136	132.72	722.8
10 KHz	1.68	24.53	45.40	36.10	25.70	270	20.44	0.477	0.0334	98.46	60.2
100 KHz	1.68	24.53	30.56	27.90	25.70	269	23.46	0.320	0.0049	1.09	5.3
1 MHz	1.68	24.53	40.68	32.68	25.70	273	30.04	0.232	0.00037	0.013	0.6

Table 2: Effect of frequency variations on electrical properties of melon seed.

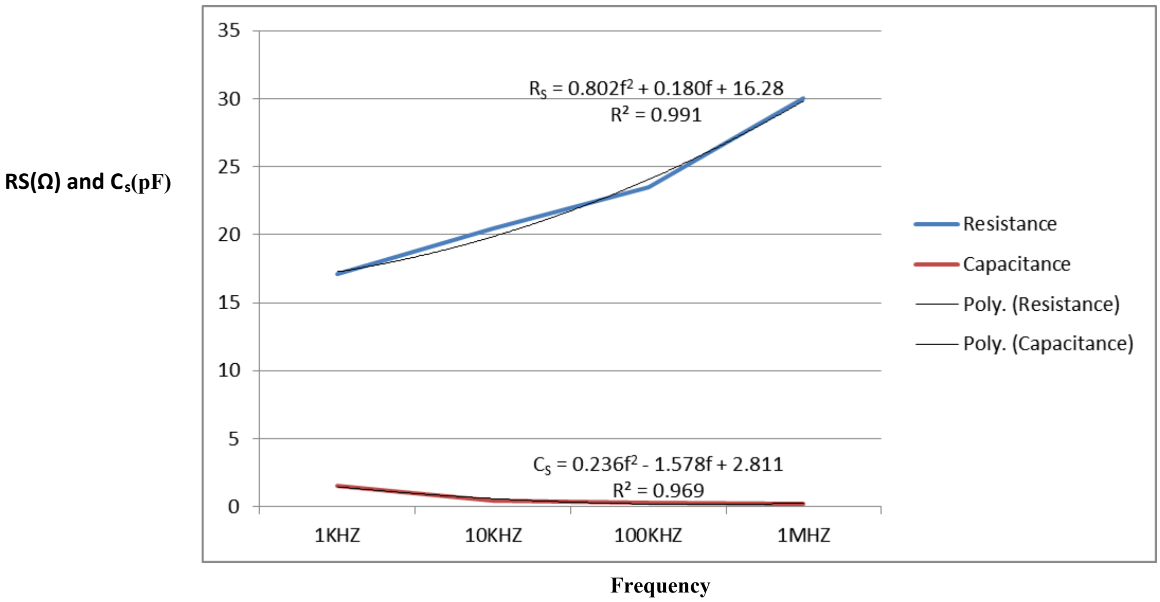

Figure 8: Effect of frequency on Resistance and Capacitance of melon seed.

A dielectric constant of 132.72 was recorded at 1 KHz, but sharply decreased to 0.013 at a frequency of 1 MHz. This implies that at low frequencies, the dipoles in the seed have time to follow the path of the electric field. Then at higher frequencies, the dipoles are quite unable to rapidly follow the field reversals, thus decreasing the dielectric constant value. These results concur with Ragni and Green [17,18]. The mathematical and graphical relationship between dielectric constant and frequency variation of melon seed is shown in Figure 9.

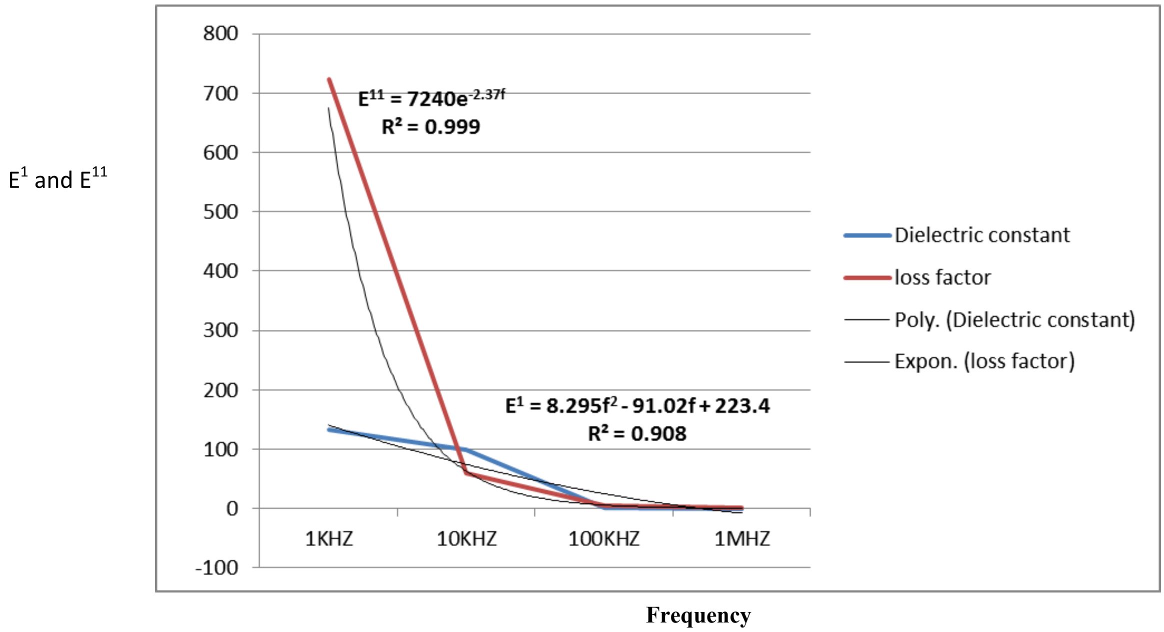

Figure 9: Relations between the variables.

In like manner, the behavior of dielectric loss factor as a function of frequency variations is depicted in Table 2. It is clear that dielectric loss factor of melon seed decreased with increase in frequency of oscillation. At 1 KHz, a dielectric loss factor of 722.8 was observed. This loss factor value then decreased to 0.6 at a corresponding frequency rating of 1 MHz. These results agree with the findings of Castro [16] and Figure 9 represents the relationship between the two variables.

Conclusion

This study investigated some electrical properties of melon seed as a function of moisture content and frequency variation using the capacitance technique. Electrical resistance of melon seeds were observed to decrease with increase in moisture level. Contrarily, electrical resistance increased positively with changes in frequency of oscillation. However, capacitance of the seed increased to a threshold at 20.42% db moisture level and dipped. Similarly, capacitance also decreased linearly with increase in frequency of oscillation. However, dielectric constant, loss factor and effective electrical conductivity increased positively with moisture changes. Conversely, loss factor and dielectric constant all tends to decrease with increase in frequency.

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