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EFFECT OF MOISTURE CONTENT ON THE ELECTRIC PROPERTIES OF SPELLED GRAINS – T. DICOCCUM

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Abstract: The article presents the results of measurements of electrical properties on sample of spelled grains with glumes, which had not been sufficiently measured. Electrical properties were measured with LCR meter.

Resistance R, impedance Z, capacity C, relative permittivity ε_r of sample of spelled in frequency interval from 20kHz to 200kHz were measured. The electric properties were measured for three values of the moisture content of the sample. The results are presented graphically and analytically. Obtained results are analyzed.

The measured values and results obtained allow concluding that resistance, impedance, capacity and relative permittivity of spelled functionally dependent on the frequency, as obtained by other authors.

The study was developed in response to the global trend to increase and control the quality of plant production and increased interest in the production and consumption of healthy and organic food (De Vita et al, 2006).

Increased productivity of traditional crops requires hard work and guidance in improving product quality. This explains the increasing interest towards spelled - T. Dicoccum, which is a valuable source of vitamins, essential amino acids and minerals

Research on electrical properties of biological materials and the results can be used when constructing the apparatus for measuring moisture content based on electrical and dielectric properties of materials.

Knowing the dependencies would allow to find the most optimal and accurate method for measuring moisture content in agricultural production.

Keywords: spelled grains with glumes, electrical properties, frequency

Introduction

Investigation of electrical properties of materials is done in many areas of science. In agricultural sciences study the electrical properties of biological materials are important both for storage in output to process control and product quality. Measurements of the electrical properties of biological materials are made quickly and the results are used to determine other properties of materials. The largest application is in measuring the moisture content of agricultural produce (grain, seeds, etc.) or dielectric losses.

Study of electrical properties is important for predicting the behavior of biological materials in the electrical field, as well as its connection to an electric circuit.

Electrical properties of the biological materials are influenced by various factors. The most important of these is water content (moisture content) and its asymmetric distribution in materials, temperature, bulk density, presence of pests, and other mechanical damage [1]. Particularly important are the dielectric properties of materials. They change by placing the material in high-frequency field. These properties are related with the percentage of moisture content in biological materials. Small changes in the water absorbed in the specimen can cause major changes in the electrical and dielectric properties of hygroscopic materials.

Using the relationship between the electrical properties of biological materials and variation of their other characteristics (water content, impurities, etc.) allows the development of measuring instruments.

It is known that electrical properties of living cells are passive and active.

From the microscopic point of view inside the cell has ion conductivity. Cell membrane has a large resistance 10^8-10^9 Ω and is not conductive. For various tissues and biological materials, electrical properties are different. In applying an alternating current biological material, have not only resistance R, but also capacity C, inductance L and total resistance - impedance Z that is greater than R.

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

Where $\omega = 2\pi f$. f is frequency of the electromagnetic field.

There are studies which found what is dependence of R, C and Z on frequency of the alternating current [1]. Dependency is a monotonically decreasing function of the type

$$R = R_0\left(\frac{f}{f_0}\right)^{-n} \qquad Z = Z_0\left(\frac{f}{f_0}\right)^{-n} \qquad C = C_0\left(\frac{f}{f_0}\right)^{-n} \qquad (1)$$

In these formulas R_0, Z_0, C_0 are constants, and n is coefficient.

From the macroscopic point of view in cell membrane there are channels through which can pass physiological ions and anions, and particle charge carriers.

The density of electric current is:

$$i_d = \sigma.E + \frac{d(\varepsilon.E)}{dt}$$

Where *E* is the electric field intensity and ε is the dielectric permittivity of the material (insulator) $\varepsilon = \varepsilon_r.\varepsilon_0$. In last formula ε_r is the relative permittivity of the substance and ε_0 = 8.85. 10^{-12} $F.m^{-1}$ is the dielectric constant.

There are studies [1,7], showing that $\varepsilon_r = f(f, t^0)$, as well as moisture content in the material $\omega\%$. This dependence is transmitted on $\varepsilon = f(\omega\%)$. Last dependence is determined by the method of connecting the water with the material, of variability in it and by chemical bonds. For bulk materials, the dependence is affected by the mass in bulk, the frequency of the electric field and temperature.

Measurement of moisture content in biological objects (grains, seeds, etc.) is the most important in storage and processing of agricultural produce. The accuracy of these measurements depends on several groups of factors. Physical properties of agricultural products affect the accuracy of measurement of moisture. Depending on the measuring method used for the physical properties can be separated: measuring the dependence of electrical resistance in hygrometers, specific resistance, conductivity, impedance, permittivity of moisture content [2].

Many methods have been used to measure moisture content especially high-frequency intervals. There have been studies of the dependence of the dielectric properties of different frequencies from 250 Hz to 12 GHz [6]. There is available information of results related with dependence of dielectric properties of wheat and seeds at low frequencies [4, 6] and microwave frequencies.

Some scientists discuss the possibility of applying dielectric method for measuring moisture in materials [2, 5]. Studies were performed [9] at low frequencies from 435 Hz to 1740 Hz to determine the dielectric constant and loss factor of rice grains. They found that $\varepsilon_r = f(\omega\%, \rho, t^0, f)$. There have been studies [4] on the application of radio frequency heating of biological materials.

One method for measuring the moisture content is the dielectric method that is based in dielectric hygrometers. On that with electrical methods, follow the behavior of the dielectric (organic material) over time for a change of the electric field.

Under the influence of electric field, dielectric is polarized and its dielectric permittivity can be measured by measuring the capacity at different frequencies of alternating current. The test substance is placed between the plates of a capacitor. One way to measure, the capacity of the condenser is bridge method by resonance and after is calculated ε of the substance. Novak [7] makes such measurings at frequencies from 1 MHz to 16 MHz . He found that in this frequency range there is a linear relationship between ε and $\omega\%$.

If the condenser is plane, then by $C = \varepsilon_r . \varepsilon_0 \dfrac{S}{d}$ for a capacitor with a dielectric (organic matter) and $C_0 = \varepsilon_0 \dfrac{S}{d}$ for air condenser, then relative permittivity can calculate from formula

$$\varepsilon_r = \frac{C}{C_0} \qquad (2).$$

The last formula allows measurement of both the capacity to find the relative permittivity of the material - the biological material.

Our studies [10] on the electrical properties of rapeseed seeds show that the dependence of the relative permittivity on the frequency is in the form of the functions (1), i.e.

$$\varepsilon_r = \varepsilon_{r0} \left(\frac{f}{f_0} \right)^{-n} \qquad (3).$$

Data for sample of study – spelled (T. Dicoccum)

Triticum turgidum ssp. dicoccon Shrank ex Schübler (synonym T. dicoccum), known as spelled a tetraploid species with grain of the genus Triticum (2n = 28, AABB). It is assumed that this is the oldest cultivated wheat cultivation, which occurred about 10,000 years BC acquired in the so-called "Fertile Crescent" (a historical region in the Middle East). In Europe, the spread of spelled first is related to the territories of Greece and Bulgaria

At present, the species occupies about 1% of the mailbox of wheat in the world, is grown mainly in Ethiopia, Iran, eastern Turkey, basin of the Volga River, the former Yugoslavia, Central Europe, Italy, Spain and India. Spelt is still an important crop for countries like India, Ethiopia and Yemen, where the grain is used for the preparation of traditional foods. According to information, it is grown in Bulgaria in limited sizes in foothill and mountain areas, mainly in the spring crop

In grain spelled established higher levels of lysine than wheat. Nutritional value of spelled, confirmed by medical records, mainly due to the high content of fiber and antioxidants, high digestibility of protein and high resistant starch content. The low glycemic index of grain types makes it suitable for diabetes. Most of these properties have been associated with higher total dietary fiber content.

In that regard, it is interesting to use spelled for treating high blood cholesterol, colitis, allergies, due to the information contained in the grain starch, fibers and antioxidant compounds. No chance to present in India grain type is used to prepare meals for diabetics and pasta to increase endurance athletes. A healthy nature of the food in which the main ingredient is the grain of T. dicoccum, is complemented by their importance as a preventive agent against colon cancer and heart disease. Spelt can be used for people suffering from celiac disease (gluten intolerance).

Selection value is ecological plasticity of the species, expressed in adaptation to grow in poor soils and climatic conditions recommended keeping the species in areas where moisture is a limiting factor. Samples spelled demonstrate high dry and heat resistance as well as high resistance to water logging of common wheat.

Analyzing the qualitative characteristics (qualitative traits, nutrition and health, resistance to disease, pests, a biotic stress) of T. turgidum ssp. dicoccon gives reason to conclude that the species is of particular interest as a source of many important genes in the selection of the ordinary winter wheat.

Of considerable interest, are the opportunities for growing the type of fertile soil in terms of organic farming, where sowing of modern conventional sort durum and bread wheat is not suitable because they cannot reveal their productive potential? Furthermore, should not be underestimated the fact that the cultivation of spelled involves both lower production costs, making it economically viable.

Materials and methods

There was test - studied spelled seeds with glumes harvest in 2012 in Bulgaria with approximately equal-sized seeds. Three measurements were made on sample with different moisture content.

Measurement were made in physics laboratory in Slovak University of Agriculture in Nitra conditions at 21^0C and humidity $\omega = 54\%$

Data of sample for testing

Sample 1 (S1)

Moisture content - $\omega = 11{,}4\%$, mass of sample - $m = 34{,}11g$,

Volume of sensor - $V = 55{,}13.10^{-6} m^3$, bulk density - $\rho = 618{,}83 \frac{kg}{m^3}$

Sample 2 (S2)

Moisture content - $\omega = 15{,}7\%$, mass of sample - $m = 35{,}21g$,

Volume of sensor - $V = 55{,}13.10^{-6} m^3$, bulk density - $\rho = 638{,}67 \frac{kg}{m^3}$

Sample 3 (S3)

Moisture content - $\omega = 24{,}1\%$, mass of sample - $m = 36{,}60g$,

Volume of sensor - $V = 55{,}13.10^{-6} m^3$, bulk density - $\rho = 663{,}89 \frac{kg}{m^3}$

These moistures content are achieved by gravity method; such samples are artificially moisturized by addition of distilled water and then dried. Mass is measured with an electronic balance accurate to 0, 0001 g.

For sensor is used plane capacitor with copper plates, which are circular with a diameter of 37,78 mm and the distance between them is 49,2 mm. The surrounding area is Plexiglas with great resistance. On top of the sensor, there is a spring so that the model is under constantly mechanical pressure. This provides a minimal presence of air between seeds of the sample.

To determine the dielectric permittivity we use the formula $\varepsilon_r = \frac{C_X - C_P}{C_0 - C_P}$, where C_X is the capacity of the condenser, that is filled with seeds, C_0 is the capacity of the empty capacitor - no seeds, C_P is the capacity of the air spaces between the seeds.

Assuming that all samples were under constant mechanical pressure, this may allow disregarding C_P .

Measurement of electrical properties R, Z, C_X for each sample having different moisture content and C_0 becomes with a LCR meter Good Will8211. The device can measure R, Z, L, C and Q factors with an accuracy of 0.05% and coefficient of dispersion D with an accuracy 0.0005%. The apparatus offers six test methods $R/Q, C/D, C/R, L/Q, Z/Q.L/R$. Frequency can be changed from f = 1 kHz to 200 kHz . The speed of measurement is 60 ms .

For each of the prepared samples are measured three times R, Z and C_X under values of frequency *f* = 20, 25, 30, 33, 40, 50, 67, 100 and 200 kHz . The empty capacitor C_0 is measured three times for the same frequencies.

With the program Graffer are built graphs $R = f(f)$, $Z = f(f)$ and $C = f(f)$ with average values of three measurements. The relative permittivity is calculated from formula (2) by the average values of the capacity of each sample at various frequencies. Dependence $\varepsilon_r = f(f)$ is plotted. The program allows determining the type of function, the relevant coefficients and the coefficient of determination.

Results and discussion

There are presented tables and graphs of results.

Table.1 Results for S1

ν, kHz	$\overline{R}, k\Omega$	$\overline{Z}, k\Omega$	$\overline{C_x}, pF$	ε_r
20	82715	5382,5	1,475	1,12
25	61110	3423,0	1,466	1,17
30	57674	3807,1	1,458	1,18
33	52920	3283,1	1,446	1,18
40	47661	2772,1	1,429	1,17
50	39529	2268,6	1,396	1,15
67	32357	1715,7	1,378	1,14
100	19957	1147,5	1,383	1,15
200	10398	564,1	1,409	1,13

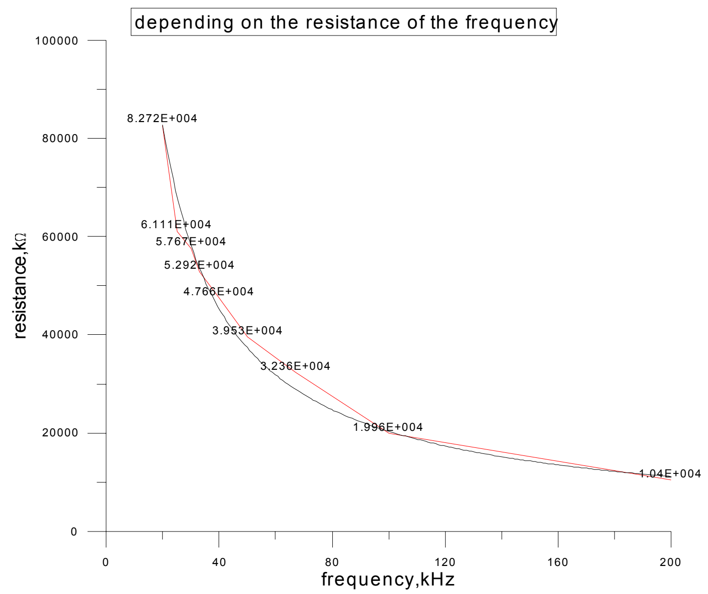
Table.2 Results for S2

ν, kHz	$\overline{R}, k\Omega$	$\overline{Z}, k\Omega$	$\overline{C_x}, pF$	ε_r
20	695,00	1422,0	6,355	4,8
25	571,73	1164,0	6,123	4,9
30	505,88	1027,0	6,169	5,0
33	439,30	893,59	6,087	5,0
40	371,61	761,99	5,917	4,8
50	299,73	634,30	5,671	4,7
67	232,57	502,50	5,275	4,4
100	160,33	365,33	4,825	4,0
200	81,69	210,64	4,073	3,3

Table.3 Results for S3

ν, kHz	$\overline{R}, k\Omega$	$\overline{Z}, k\Omega$	$\overline{C_x}, pF$
20	57,100	58,708	539,67
25	54,545	56,430	433,05
30	53,157	55,133	377,79
33	51,628	53,727	319,85
40	49,859	52,118	263,09
50	47,647	50,066	206,25
67	44,668	47,417	150,95
100	40,303	43,468	97,503
200	32,130	36,151	48,090

Graphs (Fig.1, 2, 3 and 4) from measurement of S1.



Fit 1: Power : Alternate Y = pow(X,-0.8716776236) * 1128508.301
Coef of determination, R-squared = 0.98893
Residual mean square, sigma-hat-sq'd = 0.005194

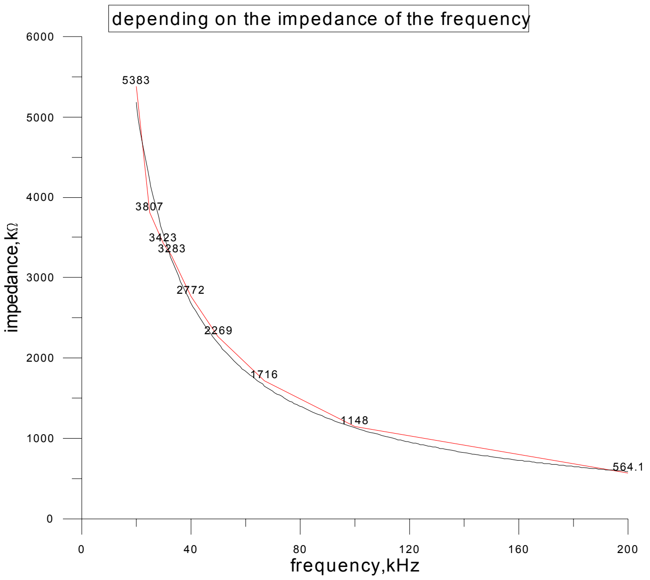
$$R = R_0\left(\frac{f}{f_0}\right)^{-n},$$

$$R_0 = 1128508.301 k\Omega,$$

$$n = 0.871677,$$

$$R^2 = 0.98893$$

Figure 1. Dependence of resistance on frequency



Fit 1: Power: Alternate Y = pow(X,-0.9455524935) * 88121.36197
Coef of determination, R-squared = 0.995321
Residual mean square, sigma-hat-sq'd = 0.00256652

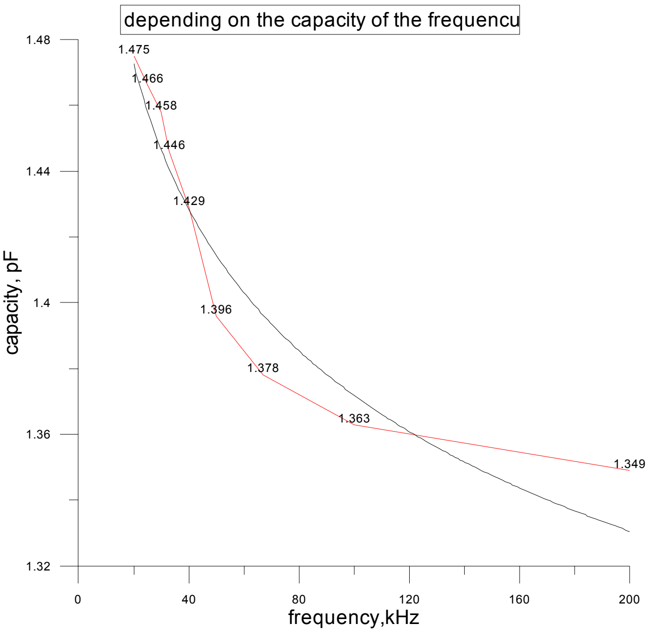
$$Z = Z_0\left(\frac{f}{f_0}\right)^{-n},$$

$$Z_0 = 88121.36 k\Omega,$$

$$n = 0.94555,$$

$$R^2 = 0.995321$$

Figure 2. Dependence of impedance on frequenc



Fit 1: Power: Alternate Y = pow(X,-0.04408420175) * 1.680609101
Coef of determination, R-squared = 0.924081
Residual mean square, sigma-hat-sq'd = 9.75021E-005

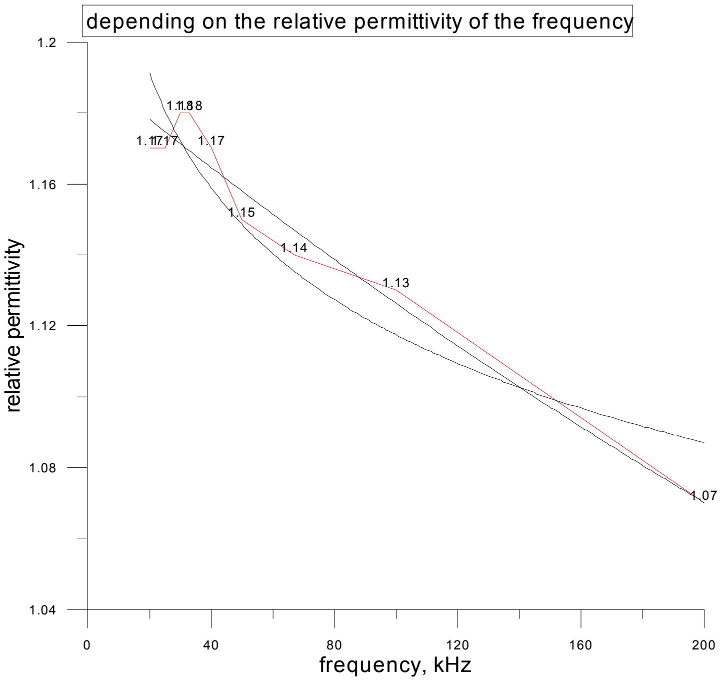
$$C = C_0 \left(\frac{f}{f_0} \right)^{-n},$$

$$C_0 = 1.6806091 pF,$$

$$n = 0.044084,$$

$$R^2 = 0.924081$$

Figure 3. Dependence of capacity on frequency



Fit 1: Power: Alternate Y = pow(X,-0.0397493177) * 1.341908148
Coef of determination, R-squared = 0.866069
Residual mean square, sigma-hat-sq'd = 0.00014921

$$\varepsilon_r = \varepsilon_{r0} \left(\frac{f}{f_0} \right)^{-n},$$

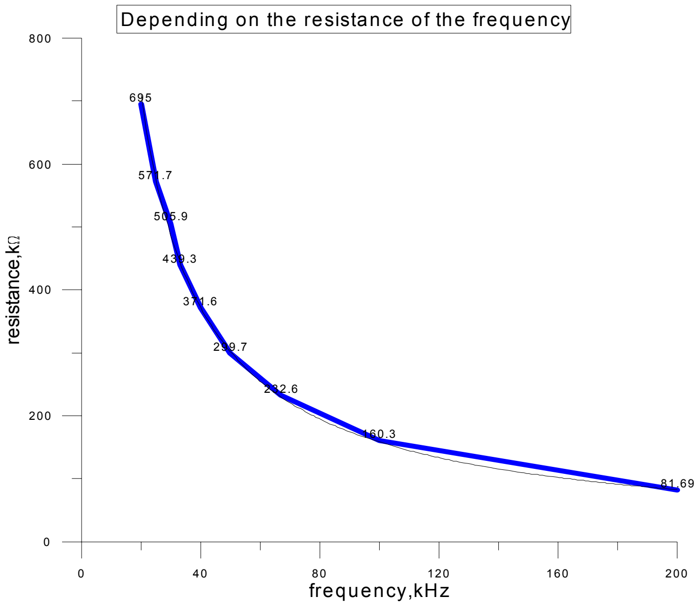
$$\varepsilon_{r0} = 1.3419,$$

$$n = 0.039749,$$

$$R^2 = 0.866069$$

Figure 4. Dependence of relative permittivity on frequency

Graphs (Fig.5, 6, 7 and 8) from measurement of S2.



Fit 1: Power: Alternate Y = pow(X,-0.932005794) * 11573.02133
Coef of determination, R-squared = 0.999243
Residual mean square, sigma-hat-sq'd = 0.000401933

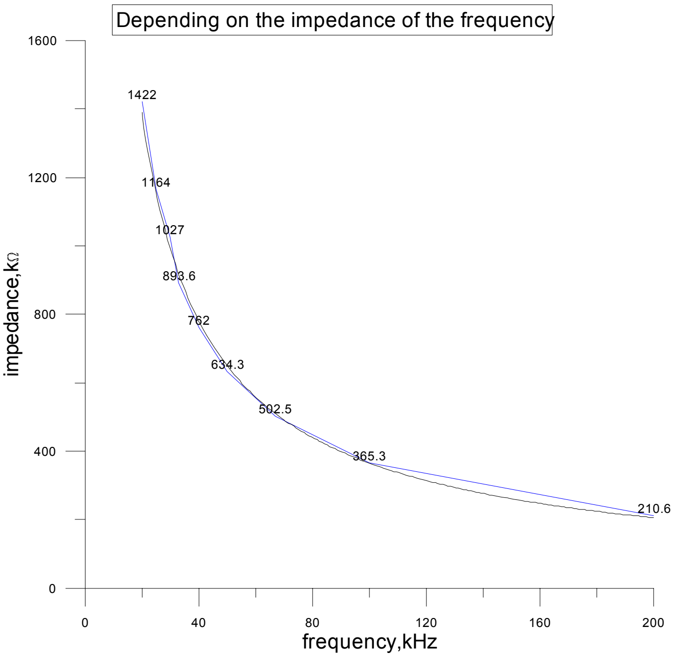
$$R = R_0\left(\frac{f}{f_0}\right)^{-n},$$

$$R_0 = 11573.021 k\Omega,$$

$$n = 0.9320058,$$

$$R^2 = 0.999243$$

Figure 5. Dependence of resistance on frequency



Fit 1: Power: Alternate Y = pow(X,-0.8294823281) * 16669.11604
Coef of determination, R-squared = 0.998494
Residual mean square, sigma-hat-sq'd = 0.000633795

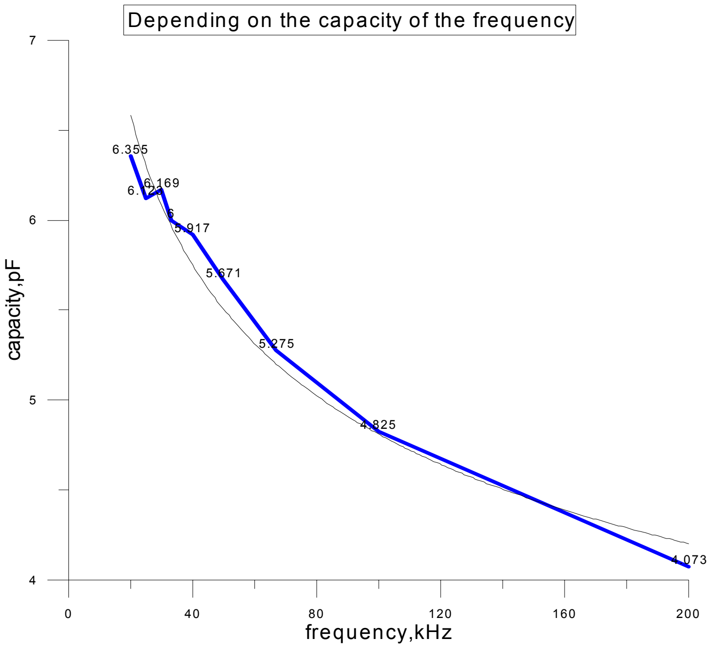
$$Z = Z_0\left(\frac{f}{f_0}\right)^{-n},$$

$$Z_0 = 16669.116 k\Omega,$$

$$n = 0{,}829482,$$

$$R^2 = 0{,}998494$$

Figure 6. Dependence of impedance on frequency



Fit 1: Power: Alternate Y = pow(X,-0.1950154347) * 11.80625356
Coef of determination, R-squared = 0.969188
Residual mean square, sigma-hat-sq'd = 0.000738341

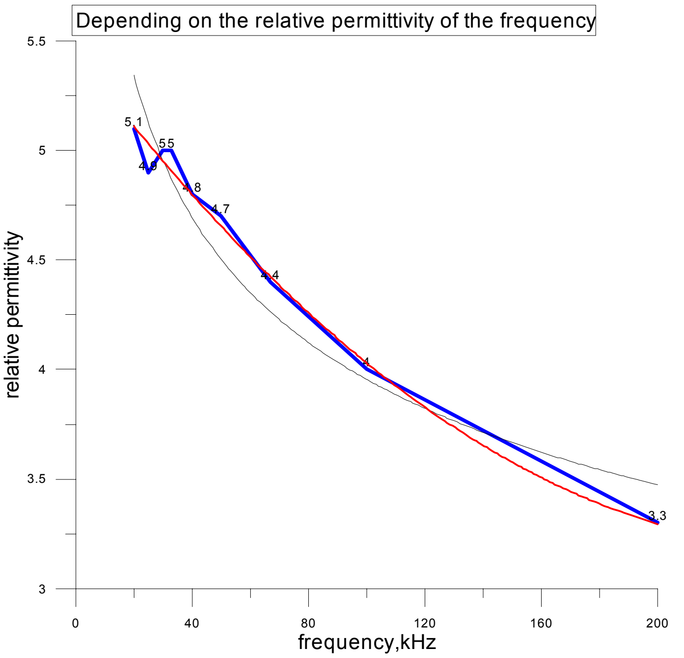
$$C = C_0\left(\frac{f}{f_0}\right)^{-n},$$

$$C_0 = 11.80625\,pF,$$

$$n = 0.1950154,$$

$$R^2 = 0.969188$$

Figure 7. Dependence of capacity on frequency



Fit 1: Power:Alternate Y = pow(X,-0.1872675316) * 9.368594932
Coef of determination, R-squared = 0.930765
Residual mean square, sigma-hat-sq'd = 0.00159302

$$\varepsilon_r = \varepsilon_{r0}\left(\frac{f}{f_0}\right)^{-n},$$

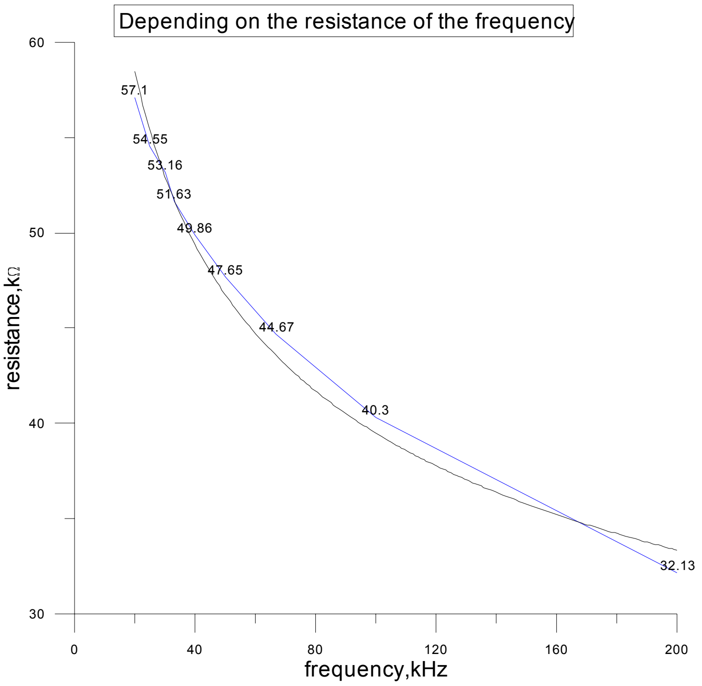
$$\varepsilon_{r0} = 9.36859,$$

$$n = 0.1872675,$$

$$R^2 = 0.930765$$

Figure 8. Dependence of relative permittivity on frequency

Graphs (Fig.9, 10 and 11) from measurement of S3.



Fit 1: Power: Alternate Y = pow(X,-0.2440619412) * 121.4863025
Coef of determination, R-squared = 0.985648
Residual mean square, sigma-hat-sq'd = 0.000529675

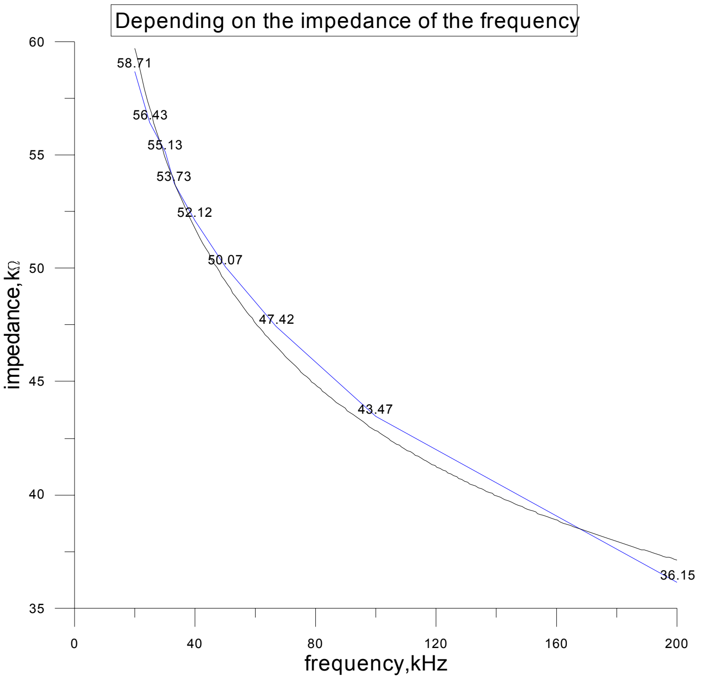
$$R = R_0\left(\frac{f}{f_0}\right)^{-n},$$

$$R_0 = 121.4863 k\Omega,$$

$$n = 0{,}24406,$$

$$R^2 = 0{,}985648$$

Figure 9. Dependence of resistance on frequency



Fit 1: Power: Alternate Y = pow(X,-0.2066071808) * 110.9184155
Coef of determination, R-squared = 0.989609
Residual mean square, sigma-hat-sq'd = 0.000273704

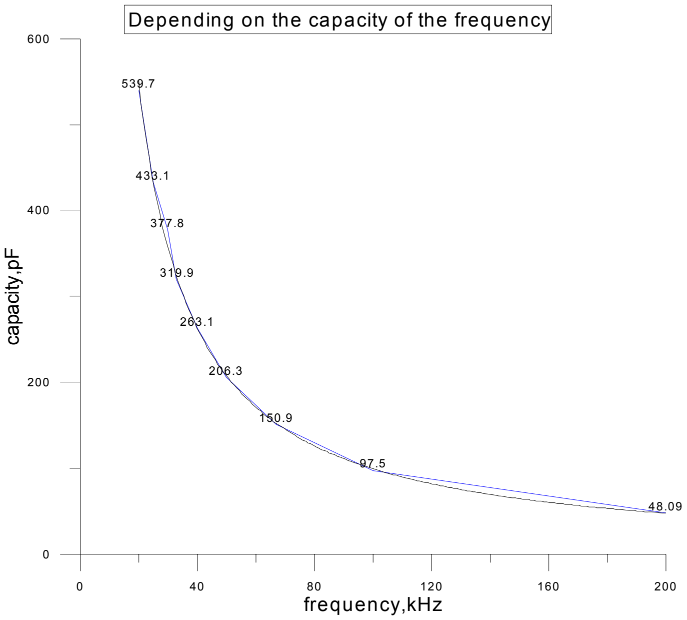
$$Z = Z_0\left(\frac{f}{f_0}\right)^{-n},$$

$$Z_0 = 110.9184 k\Omega,$$

$$n = 0{,}206607,$$

$$R^2 = 0{,}989609$$

Figure 10. Dependence of impedance on frequency



Fit 1: Power: Alternate Y = pow(X,-1.064413825) * 13359.5307
Coef of determination, R-squared = 0.999151
Residual mean square, sigma-hat-sq'd = 0.000587914

$$C = C_0\left(\frac{f}{f_0}\right)^{-n},$$

$$C_0 = 13359.5307\,pF,$$

$$n = 1.0644,\ R^2 = 0.999151$$

Figure 11. Dependence of capacity on frequency

Conclusion

The measured values and results obtained allow concluding that resistance, impedance and capacity of spelled seeds depend on the frequency as function of type (1) obtained by other authors.

The results show that with increasing moisture content of the samples, the values of R and Z decreassing. In dry materials, R and Z have higher values than materials with higher moisture content.

The values of capacity C for samples with higher moisture content are higher than dry materials.

The results for the dependence of relative permittivity on the frequency show that with increasing the frequency the relative permittivity decrease. At higher values of the moisture content, the relative permittivity has also higher values. At very high levels of moisture content $\omega = 24{,}1\%$ values of relative permittivity are unreal.

Research on electrical properties of biological materials and the results can be used when constructing the apparatus for measuring moisture content based on electrical and dielectric properties of materials.

Knowing the dependencies would allow to find the most optimal and accurate method for measuring moisture content in agricultural production.

We can conclude that the resistance, impedance, capacity and relative permittivity of spelled seeds decrease with the frequency of electric field. Other authors presented similar results for other biological materials. The relationship of the dielectric constant of spelled seeds samples provides a basis for the design of many commercial moisture-testing instruments. The results would allow programmed electrical hygrometers for the study of moisture content in agricultural production and the type of spelled seeds.

The results indicate that the selected frequency range is suitable for the study of the electrical characteristics of spelled. In the future, we will conduct studies in other frequency intervals.

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