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ELECTRICAL PROPERTIES OF DRIED QUINCES UTILIZATION
KORIŠĆENJE ELEKTRIČNIH OSOBINA OSUŠENIH DUNJA

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ABSTRACT

The aim of this study was to measure the electrical properties of dried quinces. Faculty of Agriculture of University in Novi Sad had provided the samples of dried quinces (Cydonia Oblonga Mill.) in the frame of a bilateral project. Electrical resistance, impedance and capacitance were measured by LCR meter GoodWill LCR-821. The frequencies normally used for conductivity measurement are in the range (1 – 500) kHz. Our measurements had been realized at frequencies from 100 Hz to 200 kHz. The capacitance, resistance, and impedance as well decrease with the frequency. The regression equations have the shape of decreasing power functions. The displacement between frequency dependencies of capacitance for various samples is very small. From this we can dedicate that the method of drying ensured the same properties of all quince pieces. Electrical properties can be used at the control of quince pieces identical moisture content after drying.

Key words: *electrical impedance, capacitance, frequency, dried quinces, LCR Meter.*

REZIME

Cilj ovog istraživanja bio je da se izmere električna svojstva suve dunje. Poljoprivredni fakultet Univerziteta u Novom Sadu obezbedio je uzorke suve dunje (Cidonia oblonga Mill.) u okviru bilateralnih projekata. Električni otpor, impedansa i kapacitivnost mereni su LCR-metrom Goodvill LCR-821. Frekvencije, u opsegu 1 - 500 kHz se uobičajeno koriste za merenje električne provodjivosti. Sopstvena merenja ostvarena su na frekvencijama od 100 Hz do 200 kHz. Kapacitivnost, otpornost i impedansa smanjuju se sa smanjenjem frekvencije. Regresione jednačine imaju oblik opadajuće kvadratne funkcije. Razlike između kapacitivnosti pri različitim frekvencijama za različite uzorke su veoma male. Iz ovoga može da se zaključi da metod sušenja osigurava iste karakteristike svih uzoraka dunje. Električne osobine mogu se koristiti u kontroli sadržaja vlage u uzorcima dunje posle sušenja.

Ključne reči: *električna impedansa, kapacitivnost, frekvencija, osušene dunje, LCR metar.*

INTRODUCTION

Electrical properties of biological materials can give information about the inner structure, physiological state of biological tissues. The requirements of the user industry in terms of quality purchased fruit and vegetable are growing. In addition, fruits and vegetables must meet quality standards and of course the rules of the European Union. Therefore we need constantly monitoring and control its quality from producer to consumer. The measurement of electrical properties of food can be used to get information about food composition and quality. In addition there are some food processes which are based on electrical effects. An electric current which flows through a food material will cause a temperature rise in the material. The temperature rise is due to energy dissipation by the electric resistance of the food. So knowledge of the design of the electric conductivity or resistivity is essential for this type of heating operation, which is called ohmic heating. Ohmic heating has several advantages. For example, there is no need for double walled heated vessels and no fouling on heated surfaces. Because the heat is produced inside the food, convective heat transfer is not the most important or the single heat transport mechanism. On the other hand high voltage electric pulses can damage cells and cause higher permeability of cell walls. In cases where cells of agricultural products have to be extracted, e.g. in making fruit juices or extracting sugar from beets this electric pulse treatment can increase the extraction efficacy. Electric pulse treatment sometimes is abbreviated PEF (pulsed electric fields) or HEFP (high electric field pulses) treatment (*Figura and Teixeira, 2007*).

When studying the physical properties of tissue, it is necessary to consider its non-homogeneity from the macroscopic and microscopic points of view. From the microscopic point of view, it is apparent that inside the cell is conductive because there is electric conductivity of ion type in the content of the organic and inorganic matter solutions. Electric current flow in an ionic solution is a more complex event than in a metal. However, ion current implies a transport of substance. Therefore, an externally applied dc current can not flow forever without changing the conductor. At first, changes will occur near the electrodes, but in a closed electrolytic cell with sufficiently long time the change will spread to the bulk of the electrolyte (*Grimnes and Martinsen, 2008*). The cell membranes are not conductors. From the macroscopic point of view, it is possible to regard the biological materials as non-homogeneous semi-conductors or dielectrics. A capacitive current is an ac current. In the electrode wires it is a true current of electrons charging the capacitor plates, but without electrons leaving or entering the dielectric. There is a simple relationship between the charge (Q, coulomb) on the plates, the voltage U between the plates, and the capacitance C of the capacitor

$$Q = CU \tag{1}$$

The capacitance of the capacitor is dependent on the plate area S, the distance between the plates d, and a property of the dielectric between the plates which is static permittivity ε_s (*Grimnes and Martinsen , 2008*).

$$C = \varepsilon_s \frac{S}{d} \tag{2}$$

The density and structural arrangement of the cells in biological materials and the properties of each type of tissue influence the electrical properties. Most fresh fruits and vegetables are high in water content, but normally have very poor electrical conductivity because much of the water is held immobile, trapped within the cells and the intercellular spaces within the tissue structure of these plant materials. However, whenever this cell structure is broken by such mechanisms as thermal heating, mechanical crushing, or enzymatic activity, the water containing charged ions is free to flow about serving as a mobile carrier for these charged ions, and the electrical conductivity can increase significantly. (*Figura and Teixeira, 2007*).

The characteristics of loose and porous materials are also influenced by the properties of air, which is trapped between the parts or in the pores, most especially its moisture content and temperature. The deployment of the parts in the pack, the size of parts, gappiness, contact surface and bulk density also influence the electrical properties of loose materials. Among the influential factors for porous materials the following can be involved: size and distribution of pores, porosity and bulk density. Further factors are temperature of the material, but the most significant is the influence of the presence of water, its uneven deployment in the material, different binding energy in each water bond in the material and sorption properties (*Hlaváčová, 2003*).

The water removal from fruits and vegetables is necessary for ensuring of theirs longer durability. *Babić et al.* (2002, 2007) found out that the combine method of drying, contained of osmotic and convective drying, is advantageous for ensuring dried fruit quality.

A lot of methods based on the dielectric measurements are exploited at appraisal of various fruits, vegetables or their products quality. For example *Arnold et al.* (1998) described electrical impedance methods for assessing fruit quality. Methods were minimized or compensated the influence of interfacial impedances between electrodes and plant tissue, which occur when assessing fruit or vegetable quality by electrical impedance methods. *Harker and Maindonald* (1994) related the changes in tissue resistance measured using low frequencies of alternating current to flesh firmness. *Vozáry, et al.* (1999) described the impedance parameter characterized apple bruise. *De los Reyes et al.* (2007) determined the complex permittivity of different aqueous solutions, fresh and osmotically dehydrated cherry tomatoes and related it to the products' composition.

The aim of this research was to measure the electrical properties of quinces with LCR meter using four-electrode (tetrapolar) system and also to construct graphical dependencies of electrical quantities on frequency. We tried to find potential utilization of dried quince electrical properties.

Nomenclature:

C (F)	– capacitance of the capacitor
C_0 (F)	– reference capacitance
R (Ω)	– resistance
R_0 (Ω)	– reference resistance
S (m^2)	– area of the electrode
U (V)	– voltage between the plates
Q (C)	– charge on the plates
Z (Ω)	– impedance
Z_0 (Ω)	– reference impedance
d (m)	– distance between the electrodes
f (Hz)	– frequency
f_0 (Hz)	– reference frequency
k	– constant
Greek symbols	
ε_s ($F.m^{-1}$)	– static permittivity
ω (%)	– moisture content wet basis

MATERIAL AND METHODS

Quinces *(Cydonia oblonga* Mill.) were used in our studies. The samples of quince in form of dried slices were delivered by Faculty of Agriculture of the University in Novi Sad. The method of drying was described by *Babić et al.* (2002). Samples were stored in a refrigerator at (5 – 7) °C in a room without ventilation. The samples were taken from the refrigerator and the measurements were done after stabilization at room temperature (20 – 23) °C.

The mass of slices was measured with a Sartorius Basic electronic analytical and precision balance. The moisture content of samples was determined according to standard by drying to constant mass at the temperature (103 ± 2) °C. The moisture content wet basis was calculated from mass losses. The electrical properties of thirty slices were measured with precision LCR meter GoodWill 821 in frequency range from 100 Hz till 200 kHz at voltage of 1 V. Two special plate electrodes were used as a sensor. The dried slices of quince were located between them. Each electric property was measured at all frequencies three times. Average value and standard deviation has been computed from these ones. The measured values were loaded by PC.

RESULTS AND DISCUSSION

Mass of measured quince pieces was in the interval (1.2 – 7.4) g. Average moisture content wet basis of slices was 8.58 %. The differences in moisture content between particular slices were negligible. From measured and calculated values are constructed graphical dependencies of electrical quantities on frequency. For illustration, the resistance versus frequency curves for 6 samples No. 1 to No. 6 of quinces are shown in Fig. 1.

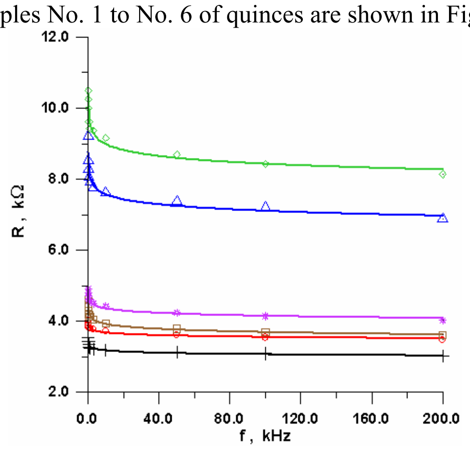

Fig. 1. Frequency dependence of dried quinces resistance, + - sample 1, m = 1.2 g; △ - sample 2, m = 1.9 g; O - sample 3, m = 2.2 g; ◇ - sample 4, m = 6.9 g; □ - sample 5, m = 7.4 g; ✳- sample 6, m = 4.4 g)

The regression equation for resistance has the shape of decreasing power function

$$R = R_0 \left(\frac{f}{f_0} \right)^{-k} \tag{3}$$

where: R – resistance, R_0 – reference resistance, f – frequency, f_0 = 1 kHz, k – constant, Z – impedance, Z_0 – reference impedance, C – capacitance, C_0 – reference capacitance.

The resistance values of all samples are in the interval (3.2 – 10.5) kΩ. In Tab. 1 are given the coefficients of regression equation (3) and the coefficient of determination for the aforementioned samples.

Table 1. Values of regression equation coefficients R_0, k and coefficient of determination R^2 for Eq. 3

Sample	R_0 , kΩ	k	R^2
quince no. 4 (◇)	9,577 83	0,027 836 5	0,977208
quince no. 2 (Δ)	8,068 03	0,027 737 8	0,930647
quince no. 6 (✳)	4,576 56	0,021 485 2	0,981738
quince no. 5 (□)	4,163 05	0,026 305 7	0,979206
quince no. 3 (O)	3,809 2	0,015 235 1	0,97536
quince no. 1 (+)	3,287 93	0,015 423 4	0,925276

In Fig. 2 is frequency dependencies of capacitance for samples of dried quinces No.1 (+), No. 3 (◇), No. 4 (Δ), measured between the special electrodes, intended for the said LCR meter.

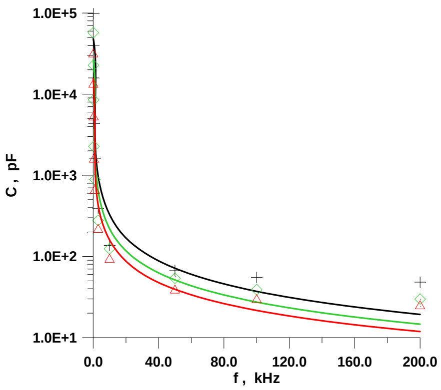

Fig. 2. Frequency dependencies of capacitance for dried quinces (+ - sample 1, m = 1.2 g; ◇ - sample 3, m = 2.2 g; Δ - sample 4, m = 5.9 g)

The following charts are shown by the power function with the similar shape as Eq. 3

$$C = C_o \left(\frac{f}{f_o} \right)^{-k} \tag{4}$$

where: C – capacitance, C_0 – reference capacitance, f – frequency, f_0 = 1 kHz, k – constant.

The constructed graph shows that the capacitance depending on the frequency has downward tendency. The capacitance values are in the range (24.4 – 98 507) pF. The displacement between frequency dependencies of capacitance for 3 samples is very small. In Tab. 2 are given the coefficients of determination for the aforementioned samples.

Table 2. Values of regression equation coefficients C0, k and coefficient of determination R2 for Eq. 4

Sample	C_0 , pF	k	R^2
quince no. 1 (+)	2 856,85	0,943 058	0,948678
quince no. 3 (◇)	1 761,48	0,904 151	0,953722
quince no. 4 (Δ)	1 165,51	0,866 06	0,958334

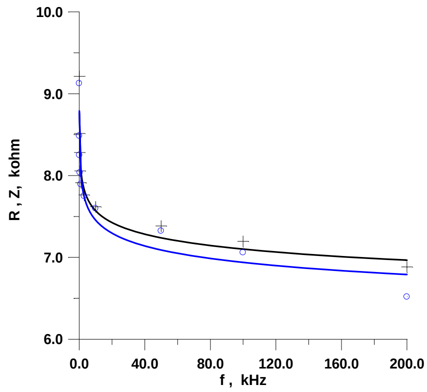

Fig. 3. Frequency dependencies of impedance (O) and resistance (+) for samples of dried quinces No.2, m = 1.9 g.

In Fig. 3 are the frequency dependencies of impedance and resistance for samples of dried quinces No.2 which show that the impedance decreases more quickly than resistance, which is caused by the capacitance of dried fruits. Impedance decrease with frequency also according to power function

$$Z = Z_o \left(\frac{f}{f_o} \right)^{-k} \tag{5}$$

where: Z – impedance, Z_0 – reference impedance, f – frequency, f_0 = 1 kHz, k – constant.

The impedance values are in the interval (2.97 – 10.5) kΩ.

CONCLUSION

Average moisture content wet basis of slices was 8.58 %. The differences in moisture content between particular slices were negligible. Mass of measured pieces was in the interval (1.2 – 7.4) g. The resistance values of all samples are in the interval (3.2 – 10.5) kΩ, capacitance values are in the range (24.4 – 98 507) pF, impedance values in interval (2.97 – 10.5) kΩ.

The results of the measurements are specific electrical properties depending on frequency. Each electric property was measured at all frequencies three times. Standard deviations were very small for every quantity. We found out that the resistance, capacitance and impedance of the measured samples decrease with frequency according to power function (Eq. 3, 4, 5) in measured frequency range. The impedance decreases more quickly than resistance, which is caused by the capacitance of dried fruits. The coefficients of determination of the regression equations reached high values for all measured quantities and materials. The displacement between frequency dependencies of capacitance is very small. From this we can dedicate that the method of drying ensured the same properties of all quince pieces. Electrical properties can be used at the control of quince slices identical moisture content after drying.

We can conclude that the measured electrical properties are investigated to reveal the quality of food materials and quality of drying as well. Measured values and designed graphs can be used to determine the quality of dried quinces.

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