1. Jacek MAJCHER[1]

Lublin University of Technology (1)
ORCID: 1. 0000-0002-7030-6844

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Determination of rapeseed moisture based on electrical parameters - a review

***Abstract**. The paper presents a review of methods for determining rapeseed moisture using electrical parameters. Resistance, capacitive and microwave methods are described. In addition, several methods for measuring the moisture content of individual rapeseeds were presented. The presented methods allow for an immediate reading of moisture and are non-destructive methods.*

***Streszczenie.** W pracy przedstawiono przegląd metod do wyznaczania wilgotności nasion rzepaku za pomocą parametrów elektrycznych. Opisano metody rezystancyjne, pojemnościowe czy też mikrofalowe. Dodatkowo przedstawiono kilka metod do pomiaru wilgotności pojedynczych nasion rzepaku. Przedstawione metody pozwalają na natychmiastowy odczyt wilgotności i są metodami nie niszczącymi. (**Oznaczanie wilgotności rzepaku na podstawie parametrów elektrycznych – przegląd**)*

Keywords: rapeseed, moisture, electrical parameters
Słowa kluczowe: rzepak, wilgotność, parametry elektryczne

Introduction

Rapeseed is one of the key oil crops in the world. According to the Food and Agriculture Organisation of the United Nations in 2017, rapeseed is second only to soybeans in the production of vegetable oil. The world leader in rapeseed production in 2017 was the European Union with a production of 22 million tonnes [1]. Rapeseed is an extremely valuable raw material used in many industries. The most popular application is the use of rapeseed for the production of biofuels. Rapeseed oil as a biofuel is used in its natural form and in the form of methyl ester [2, 3]. Rape seeds are also used in the food industry (rapeseed oil), the chemical industry and as animal feed [4].

To be able to use the full potential of rapeseed, care should be taken to store it properly. As presented in paper [5], the storage process depends strictly on the temperature and moisture of the seeds. While maintaining the right temperature in silos is not economically justified, maintaining the desired moiture of seeds is. The moisture of seeds in closed warehouses does not change significantly, so it is necessary to ensure the correct moiture of rapeseed at the time of its harvest. Rapeseed is best stored when its moisture content is less than 7% [6]. For this purpose, rape moisture must be constantly monitored during harvesting using available measurement methods. Another argument in favour of measuring seed moisture content is the close correlation between price and seed moisture content on rapeseed markets [7]. Instant moisture reading is especially important for precision farming, which allows to adjust machine settings to current field conditions. Seed moisture is also a key parameter determining the date of rapeseed harvest.

There are many methods and techniques available on the market for measuring rapeseed moisture. The method considered as reference is the oven-drying method. It consists in measuring the weight of a rapeseed sample before and after drying. The moisture content of the material is obtained from the weight difference. Rapeseed, according to [8] PN-EN ISO 665:2020-09, should be dried at 103^{o}C for 3 hours. The above method, despite its accuracy, is used only in laboratory conditions, due to its time-consuming nature. In field conditions, methods that allow for immediate moisture readings are preferred, even at the expense of measurement accuracy. Therefore, in such applications, the so-called indirect tests, which consist in determining the moisture content of rape seeds on the basis of other parameters. Other indirect methods include:

- optical method – using infrared radiation,
- acoustic,
- magnetic,
- chemical,
- dielectric [5].

The aim of the work is to synthesise information on rapeseed moisture measurement based on its electrical parameters.

Electrical parameters of rape seeds

Rape seeds, being a biological material, are classified as porous material. Due to their complex structure, they bind relatively large amounts of water. What is more, some of the water in the case of rape seeds is closely related to the surface of the seeds. On the other hand, part of the water contained inside the seeds can be locked in the solid phase. Figure 1 shows the anatomical structure of rape seeds.

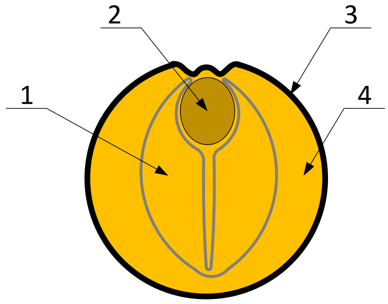

Fig.1 Anatomy of rape seeds: 1 - inner cotyledon, 2 - embryo, 3 - hull, 4 - outer cotyledon [9]

In terms of electricity, rape seeds are classified as dielectrics. Because the anatomical structure of seeds is heterogeneous, they should be classified as heterogeneous dielectrics.

In the case of using the electrical properties of rape seeds, several electrical parameters are used to determine seed moisture on their basis:

- resistance,
- capacity,
- dielectric permittivity,
- dielectric loss factor.

The dielectric permittivity is a complex value $\varepsilon = \varepsilon' - j\varepsilon''$, where the real part ε' is the dielectric constant and the imaginary part ε'' represents the loss factor. The high resolution of the indirect measurement using the dielectric permittivity results from the large difference in the permeability of water in the "free" state, which is about 80, and the other components of rapeseed, whose permittivity is in the range of 3 to 5. Due to the high content of bound water, it relaxes more slowly than free water, which leads to a reduction in the so-called effective permittivity of water which may cause incorrect moisture readings [7, 10].

Electrical methods of rapeseed moisture measurement

Several methods are known for measuring the electrical parameters of seeds, including rape seeds. Among them we can distinguish, among others:

- electrical conductivity
- resistance method,
- impedance method,
- capacitive method.
- microwave method [5].

The resistive method was described at the beginning of the 20th century in [11]. It consists in measuring the resistance of seeds placed between two parallel plates. These boards are powered by direct current. In this case, the resistance of the seeds increases as their moisture content decreases. In such a measuring system, attention should be paid to the influence of the electromagnetic field on the correctness of reading values on individual meters [12]. Figure 2 shows the dependence of the resistance on the moisture of rape seeds placed between two parallel plates measuring 100 x 100 mm spaced 8 mm apart.

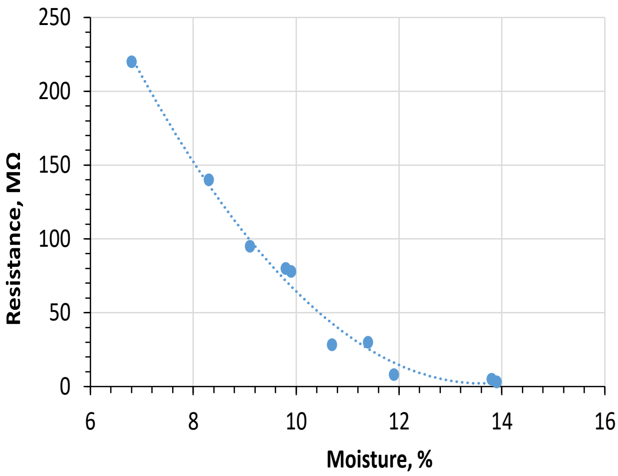

Fig. 2 Dependence of resistance on rapeseed moisture

Similar results were presented in paper [13]. An extension of the above method is supplying the electrodes with alternating current. In this case, in addition to resistance, capacitance and inductance are also determined. In this way it is possible to determine the impedance of the seeds:

$$Z = \sqrt{R^2 + (X_L - X_c)^2}$$

Figure 3 shows a test stand where the resistance and capacitance in the frequency range of 100 Hz – 100 kHz were determined. The Fluke PM 6304 RLC meter and a 100 x 100 mm flat capacitor spaced 8 mm apart were used for the measurement. The results of the impedance measurement are shown in Figure 4.

Fig 3. Experimental set-up

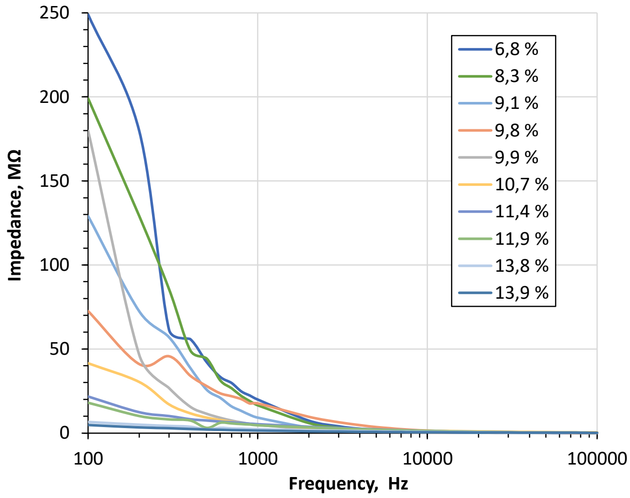

Fig 4. Impedance of rape seeds as a function of frequency for different moisture

A similar experiment can be found in paper [14], where it was found that the resistance and impedance of rapeseed (in the frequency range from 1 to 200 kHz) decreases with increasing frequency. The capacitance and dielectric permittivity behave similarly. The research discussed shows that for the frequency of 200 kHz, dielectric permittivity is an exponential function of moisture:

$$\varepsilon = \exp(0{,}276406 \cdot moisture) \cdot 0{,}168838$$

Measurements in radio and microwave frequencies

In microwave methods, the moisture content in seeds is measured by the attenuation of microwave radiation passing through the test medium. The measuring system may consist of a transmitting antenna connected to the microwave generator and a receiving antenna connected to the measuring device. Between the antennas is the test object in the form of seeds. The basis of this method is the dependence of microwave energy attenuation on moisture. In this case, the higher the moisture content of the tested seeds, the less signal goes to the measuring device [15].

Determination of rapeseed moisture based on complex dielectric permittivity spectrum. These studies are described in [16]. Measurements were made in the frequency range of 20 MHz – 3 GHz using a vector network analyser to which the coaxial transmission-line cell presented in Figure 5 was connected.

The research carried out shows that the moisture content of seeds closely depends on the part of the real dielectric permittivity. In the frequency range shown, there are visible changes in the dielectric permittivity spectrum depending on the moisture. In a similar frequency band, tests of electrical parameters of rapeseed described in [18] were carried out. In this case, the authors use several frequencies from the ISM (Industrial, Scientific and Medical) range: 13, 27, 40, 915 and 2450 MHz. An open-ended coaxial probe was used for the measurements. To avoid air gaps, rape seeds were pressed and placed under the probe. Then, electrical parameters such as dielectric constant ε' and loss factor ε'' were determined depending on the moisture content of rape seeds.

Another example of rapeseed moisture measurement is the use of a vector network analyser and a suitable probe. Examples of probes are shown in Figure 6.

Fig. 5 Cross section of the measurement cell [17]

Fig. 6 a) open ended probe, b) seven rod probe, c) antenna probe

In this method, the dielectric permittivity spectrum is determined. The measurement system is shown in Figure 7. It consists of a vector network analyser (Libre VNA) and an antenna probe.

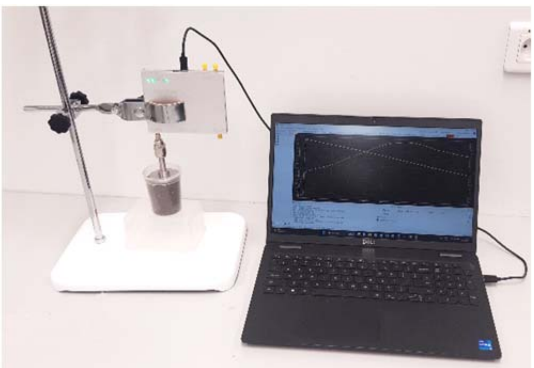

Fig. 7 Stanowisko pomiarowe z sondą antenową i wektorowym analizatorem sieci

Based on the obtained measurement results, it is possible to determine the dielectric constant ε' and loss factor ε''. Example values are given in Figure 8.

Another example using the microwave technique to test the moisture content of individual rapeseeds is the sensor proposed in [19]. It consists of a six-port reflectometer operating at 2.4 GHz. The measurement of the moisture content of individual rapeseeds is based on multiple measurements of a complex reflection coefficient A (Fig. 9).

This coefficient is determined in several places of the transmission line so that the measurement is insensitive to the position of rape seeds along the transmission line (Fig. 10).

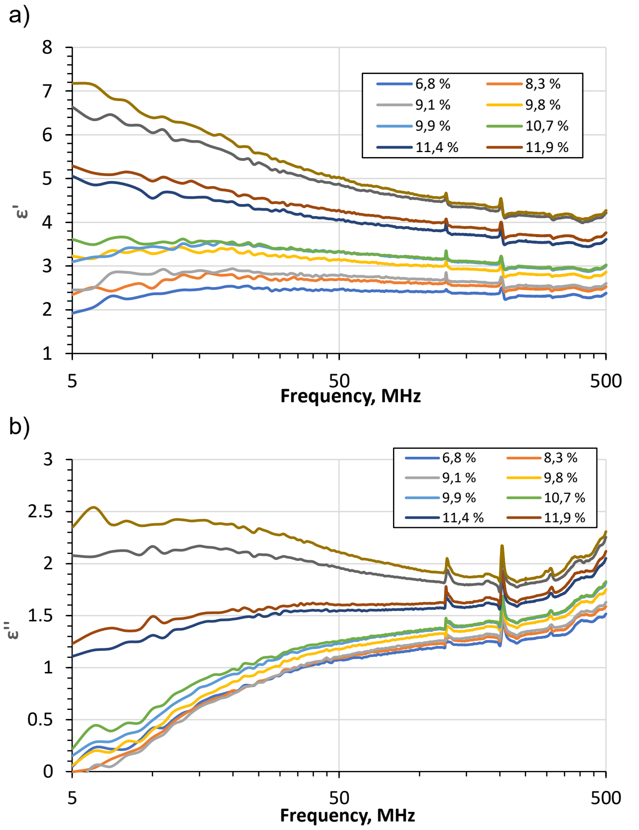

Fig. 8 Dielectric permittivity spectrum a) real part, b) imaginary part

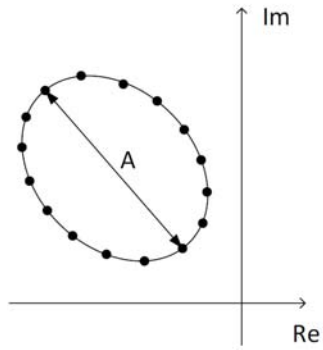

Fig. 9 Example of a complex plane of the measured values of coefficient A

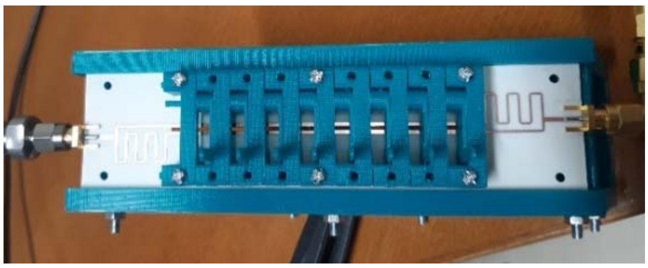

Fig. 10 Seed moisture measurement sensor constituting a transmission line

A different approach to determining rapeseed moisture content was proposed in [20]. In the experiment, rape seeds hit a piezoelectric plate and, based on the shape of the signal generated by the plate, a coefficient is read, which is correlated with rapeseed moisture (Fig. 11).

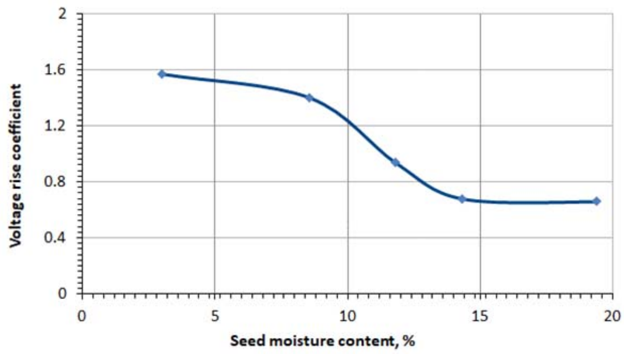

Fig. 11 Dependence of voltage rise coefficient on rapeseed moisture

Conclusion

The use of electrical parameters of rape seeds to determine its moisture content belongs to the group of indirect measurements. The advantage of this type of measurement is the almost immediate reading of the value. This is particularly important in precision farming and allows for constant monitoring of moisture during the entire technological process of rapeseed processing.

Due to the increasing availability and accuracy of measuring devices, measuring devices operating at microwave frequencies of several GHz are becoming more and more common. Due to this frequency range, measurement becomes selective and more precise.

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***Authors**: dr inż. Jacek Majcher, Lublin University of Technology, Department of Electrical Engineering and Electrotechnologies, Nadbystrzycka 38A, 20-618 Lublin, e -mail: j.majcher@pollub.pl*

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