The separation assessment of small-seeded mixtures of agricultural crops

S Kovalyshyn¹, V Ptashnyk¹, O Shvets¹, F Ivashchyshyn², B Nester¹, R Kasner³ and P Urbańska³

¹Lviv National Agrarian University, Department of Mechanics and Power Engineering, Vol. Velykogo str., 1, Dubliany, 80381, Ukraine
²Lviv Polytechnic National University, Department of Applied Mathematics and Fundamental Sciences, St. Bandery str., 12, Lviv, 79013, Ukraine
³University of Science and Technology in Bydgoszcz, Bydgoszcz, Poland

E-mail: stkovalyshyn@gmail.com

Abstract. The paper confirms that the effective separation of small-seeded mixtures of crops can be achieved if we use electrical separation methods that take into account the difference in electrical conductivity and dielectric constant of the components, their ability to receive and give a charge etc. Having examined electrical conductivity and polarization properties of winter oilseed rape and Galium aparine seeds by the method of impedance spectroscopy, it was found out that the frequency dependence of the real part of their complex resistance is of the same type and has a decreasing character. The maximum capacity of winter oilseed rape is 50% higher than the corresponding capacity of Galium aparine, and the maximum accumulation of charge by seeds is observed in the frequency band for which the real part of the complex resistance takes close values for both Galium aparine and winter oilseed rape. The revealed difference in electrical conductivity and dielectric constant of the studied seeds of winter oilseed rape and Galium aparine causes different charges, which is one of the main conditions for their effective separation in electric separators, which use an electric field of corona discharge as an additional working body.

1. Introduction

The seed industry is of strategic importance in providing agricultural producers with high yielding variety seeds.

In the structure of sown areas under agricultural crops, almost 20% is occupied by small-seeded crops. These include those for which the weight of a thousand seeds does not exceed 5 g. This condition is met by a number of oilseeds, fodder, vegetables, industrial and individual cereals. Increasing their yield is impossible without a sufficient amount of high-quality sowing material [1-4], which in terms of sowing qualities and quantitative content of difficult-to-separate weed impurities would meet the requirements of existing standards. These weed impurities, seeds with varying degrees of damage or biologically defective low-quality seeds are very similar to the main crop in most physical and mechanical properties, so it is almost impossible to separate them using existing separating machines.

It is possible to create fundamentally new separation machines or to improve the existing ones by using the principle of superposition of forces of different physical nature [5-7]. Due to this, the separation takes place not only according to the physical and mechanical properties of the components...
of the seed mixture, but also to the internal biochemical ones [8]. This can be achieved by using electric fields during separation [9], [10], which is, for example, an effective method for separating fine mixtures as shown in the work [11].

The physical, mechanical and biological properties of the seed are closely related to its electrical properties. Therefore, in order to increase the efficiency of separation from difficult-to-separate seed mixtures of crops of weed impurities or various damaged, biologically defective seeds, it is advisable to use electrical separation methods that take into account the difference in electrical conductivity and dielectric constant of the components of the mixture, their ability to receive and give a charge etc. Due to the information about the electrical properties of the components of seed mixtures, it is possible to substantiate the designs and parameters of machines for their separation, which use an electric field as an additional working body. This has been pointed out by a number of researchers in their studies, in particular [12-14].

Recently, physical methods of studying the electrical characteristics of the seed material are increasingly used to determine its physiological potential and sowing qualities. This greatly simplifies the experimental techniques and reduces the time required, for example, to determine seed germination.

The method of determining the physiological potential of seeds by their electrical conductivity has become widespread in practice. The sample size and the range of possible values of electrical conductivity are substantiated in works [15], [16]. In works [17], [18] the influence of temperature and humidity of seeds on results of measurement of their electrical conductivity is described and methods of their accounting are offered. The literature presents the experience of experimental determination of electrical conductivity of soybean [19], peas [17], Schinus molle [20] seeds and describes its correlation with their sowing qualities, determined by standard methods.

Some researchers attach great importance to the study of electro-physical parameters of seeds that have undergone electrical stimulation and electroseparation. Thus, work [21] shows the change in electrical conductivity of millet seeds under the action of corona discharge field treatment.

The study of electrical parameters also helps to detect changes in the structure of the seed or to assess the degree of its injury. Thus, in work [22] the dielectric constant and the tangent of the dielectric loss angle in the seeds of winter oilseed rape and Galium aparine were investigated to assess the possibility of their electrical separation. For such studies, low [23] and high [24] frequencies are used, as well as measuring cells of various designs.

However, the results of such studies are isolated and for their generalization it is necessary to develop a physical model of the passage of electric charge through the seeds and to confirm it by control experimental methods.

2. Research methods

In order to determine the divisibility of the seed mixture of winter oilseed rape and Galium aparine by electrical properties, their electrical conductivity and polarization properties were studied by impedance spectroscopy.

Impedance studies were performed in the frequency range $10^{-3} - 10^6$ Hz using the measuring system AUTOLAB (ECO CHEMIE) equipped with computer programs FRA-2 and GPES.

Proceeding from the conditions of the experiment and the design of the measuring cell, the study was carried out in the frequency range $10^2 - 10^6$ Hz. The low-frequency limit was limited because the dry grain substance was studied, and the upper limit was limited by the capabilities of the measuring complex.

Measurements of impedance curves were carried out in a conductometric cell of dry bulk type with stainless steel electrodes. The interelectrode distance was 2 cm and the contact area of the electrodes was 25 cm². Thus, the bulk volume of the studied samples was 50 cm³ for all examined seed species. Before measurement, the seeds were dried in an oven for 24 hours to the humidity of 10 percents. The humidity of the samples was monitored with a moisture meter.
3. Results and discussion
Experimental measurements of electrical conductivity and polarization properties involved the construction of impedance hodographs. From the obtained frequency dependences of the real component of the complex impedance, presented in Figure 1, it is seen that the largest difference Re \( Z \) for the studied seeds of winter oilseed rape and its main contaminant of Galium aparine is achieved in the range of 1-10 kHz, and the maximum difference does not exceed 50 \%.

![Figure 1](image_url)

**Figure 1.** Frequency dependences of the real part of the complex resistance of the studied seeds

Despite the slight difference in values, the frequency dependence of Re \( Z \) for both types of grains is the same and has a decreasing character. This indicates the same mechanisms of charge transfer - the main contribution is made by hopping conductivity. The main barrier to charge transfer is the contact between the grains. Under such conduction mechanisms, it is important to investigate the imaginary component of complex electrical conductivity, which, as shown in the Nyquist diagrams (Figure 2), takes on a pronounced capacitive character. To analyze the obtained impedance dependences, the Nyquist diagrams were modeled according to the equivalent electrical circuit presented in the insertion (Figure 2). The R/CPE link reflects the transfer of electric charge through the contact between the grains. Since the center of the semicircle does not lie on the abscissa axis, the capacitive type constant phase element (CPE) is used in the equivalent electrical circuit [25]. It simulates an unevenly distributed capacity due to the presence of vacancies or impurity defects that provide hopping conductivity. The next element C simulates the accumulation of electric charge on the surface of the seeds. The calculated values of the elements of the equivalent electrical circuit are presented in Table 1.

|         | CPE-\( T \), F  | CPE-\( P \) | R, Ohm | C, F  |
|---------|----------------|-------------|--------|-------|
| Galium aparine | 2.145E-10     | 0.75317     | 5.0143E6 | 7.112E-12 |
| Winter rape | 1.060E-10     | 0.80213     | 8.0148E6 | 1.025E-11 |
For the purpose of the more detailed analysis we will consider frequency dependences of the measured capacity (Figure 3). It should be noted that the capacitance values almost reach the corresponding values of $C$ for the equivalent electrical circuit (Table 1).

![Nyquist diagram for oilseed rape and Galium aparine seeds](image1)

**Figure 2.** Nyquist diagrams constructed for oilseed rape and Galium aparine seeds. The points represent the experimental data, and the curve - the simulated dependences. The insertion shows an equivalent circuit diagram for both hodographs.

![Frequency dependence of capacity](image2)

**Figure 3.** Frequency dependences of the capacity of winter oilseed rape and Galium aparine seeds.
As we can see from Figure 3, the maximum capacity of winter oilseed rape is 50% higher than the corresponding capacity of Galium aparine. However, it is interesting to note that the maximum capacity is observed in the frequency band for which the value of Re Z is similar to both types of seeds.

An important parameter of the accumulation of electric charge by seeds is the tangent of the angle of electric loss, which must take values less than one. This is confirmed by the dependences shown in Figure 4. It can be noted that as in the case of the frequency dependence of the real part of the complex resistance, tg δ takes close values for both types of seeds with the largest difference in their capacity.

![Figure 4. Frequency dependences of the tangent of the dielectric loss angle for oilseed rape and Galium aparine](image)

Since the tangent of the dielectric loss angle takes values less than one in the investigated frequency range, the assumption is confirmed that the electric field can serve as an additional working body during the separation of small-seeded mixtures in electro-corona separators (Figure 5).

![Figure 5. Schematic diagram of the mechanism of operation of the electrical separator: 1 – corona electrode; 2 – movable inclined separating plane; 3, 4 – grain receivers](image)
The principle of their work is based on the ability of seeds to receive and give a charge. In the process of separation, the seed material passes through the corona electrode. Once in the area of the electric field corona discharge, the components of the seed mixture receive a different charge, the value of which depends on their physical, mechanical and electrical properties. The strength of the electrical interaction between the seed and the working surface will be directly proportional to the magnitude of the electric charge accumulated by the seed. For the most efficient separation, it is necessary to determine the conditions under which the difference between the values of the accumulated charges of the components of the separation mixture (in this case, winter oilseed rape and Galium aparine seeds) will be the largest.

4. Conclusions
It has been established that the frequency dependence of the real part of the complex resistance of the studied seeds of winter oilseed rape and Galium aparine is of the same type and has a decreasing character, which indicates the hopping character of the conductivity. That is, the main barrier to the transfer of an electric charge during electroseparation is the contact zone between the individual grains.

It has been determined that the maximum capacity of winter oilseed rape is 50% higher than the corresponding capacity of Galium aparine, and the maximum accumulation of the seed charge is observed in the frequency band for which the real part of the complex resistance takes close values for both Galium aparine and winter oilseed rape.

The revealed difference in electrical conductivity and dielectric constant of the studied seeds of winter oilseed rape and Galium aparine causes different charges, which is one of the main conditions for their effective separation in electric separators, which use an electric field of corona discharge as an additional working body.

References
[1] Kharchenko S, Kovalishin S, Zavgorodniy A, Kharchenko F and Mikhaylov Y 2019 Effective sifting of flat seeds through sieve, INMATEH-Agricultural Engineering 58(2) 17-26
[2] Flizikowski J, Kruszelnicka W, Tomporowski A and Mroziński A 2019 A Study of Operating Parameters of a Roller Mill with a New Design, AIP Conference Proceedings 2077 UNSP 020018
[3] Lewandowska S and Kozak M 2017 Current Situation of Seed Production in the South Western Part of Poland, 13th Scientific and Technical Seminar on Seeds and Seedings, Prague, Czech Republic, February 02
[4] Nardi M 2016 The role of the seed sector in Italy for a modern and competitive agriculture, Italian journal of agronomy 11(2) 137-142
[5] Basiry M and Eshaghbeygi A 2012 Cleaning and charging of seeds with an electrostatic separator, Applied Engineering in Agriculture 28(1) 143-147
[6] Kowalyszyn S, Shvets O, Grundas S and Tys J 2013 Use of electro-separation method for improvement of the utility value of winter rapeseeds, International Agrophysics 27(4) 419-424
[7] Kowalyszyn S, Dadak V, Sokolyk V, Grundas S, Stasiak M and Tys J 2015 Geometrical and Friction Properties of perennial grasses and their weeds in view of an electro-separation method, International Agrophysics 29(2) 185-191
[8] Kruszelnicka W, Marczuk A, Kasner R, Baldowska-Witos P, Piotrowska K, Flizikowski J and Tomporowski A 2020 Mechanical and processing properties of rice grains, Sustainability 12(2) 552
[9] Fattahi S H, Abdollahpour S, Ghassemzadeh H, Behfar H, and Mohammadi S A 2017 Sunflower’s seed separation in high-intensity electric field, Agricultural Engineering International: CIGR Journal 19(2) 193-199
[10] Fattahi S H, Abdollahpour, Ghassemzadeh H, Behfar H, Mohammadi S and Mohammadi S A
2017 Regression model of sunflower seed separation and the investigation of its germination in corona field, *Agricultural Engineering International: CIGR Journal* 19(2) 187-192

[11] Chabecki P, Bordun I and Ivashchyshyn F 2019 Highly dispersed carbon powder separation by triboelectric method, *Przegląd Elektrotechniczny* 95(1) 81-84

[12] Li F, Zhang X, Li X and Wang H 2013 Effects electric field processing and dielectric separation on cotton seed germination rate and seedling mass, *Transactions of the Chinese Society of Agricultural Engineering* 26(9) 128-132

[13] Xu J, Tan M, Zhang C and Li F 2013 Improving paddy seed vigor by corona discharge field processing and dielectric separation, *Transactions of the Chinese Society of Agricultural Engineering* 29(23) 233-240

[14] Ciobanu V, Visan A, Paun A and Bogdanof G 2017 Experimental research regarding magnetic separation of seeds after their surface conditions using moistening liquids, 16-th International Scientific Conference on Engineering for Rural Development, Jelgava, Latvia, May 24-26, pp 1000-1005

[15] Binsfeld J, Barbieri A, Huth C, Cabrera I and Henning L 2014 Use of bioactivator, biostimulant and complex of nutrients in soybean seeds, *Pesqui. Agropecu. Trop.* 44(1) 88-94

[16] Azeredo G, Paula R and Valeri S 2016 Electrical conductivity in Piptadenia moniliformis benth. Seed lots classified by size and color, *Revista Arvore* 40(5) 855-866

[17] Ferreira L, Fernandes N, Aquino L, da Silva A, Nascimento W and Leão-Araújo E 2017 Temperature and seed moisture content affect electrical conductivity test in pea seeds, *Journal of Seed Science* 39(4) 410-416

[18] Souza A, Chaves M, Barbosa R and Clement C 2018 Local ecological knowledge concerning the invasion of Amerindian lands in the northern Brazilian Amazon by Acacia mangium (Willd.), *Journal of Ethnobiology and Ethnomedicine* 14(33)

[19] do Prado J, Krzyzanowski F, Martins C and Vieira R 2019 Physiological potential of soybean seeds and its relationship to electrical conductivity, *J. Seed Sci.* 41(4) 407-415

[20] Delazeri P, Garlet J and Souza G 2016 Electrical Conductivity Test in Batches of Schinus molle L. Seeds, *Floresta e Ambiente* 23(3)

[21] Wang J, Song H, Song Z, Lu Y, Yan Y and Li F 2020 Effect of Positive and Negative Corona Discharge Field on Vigor of Millet Seeds, *IEEE Access* 8 50268-50275

[22] Kovalyshyn S, Dadak V, Ptashnyk V, Shvets O, Łuczycka D, Dróżdż T, Kielpasa P and Wesołowski M 2020 The Study of Electrical Properties of Components of a Winter Rape Seed Mixture, *Przegląd Elektrotechniczny* 2020(1) 60-64

[23] Vijay R, Jain R and Sharma K 2015 Dielectric spectroscopy of grape juice at microwave frequencies, *International Agrophysics* 29 239-246

[24] Kumar A, Goel A, Kumar R, Ojha A, John J and Joy J 2019 Dielectric characterization of common edible oils in the higher microwave frequencies using cavity perturbation, *Journal of Microwave Power and Electromagnetic Energy* 53(1) 1-9

[25] Stoynov Z, Grafov B and Savvova-Stoynova B 1991 Electrochemical impedance, Nauka, Moscow, Russia