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A measuring instrument for analyzing the behavior of seeds of selected plant species exposed to a uniform electric field

***Abstract**. The article reviews electrical separation techniques for processing seed mixtures and proposes a measuring instrument for analyzing the behavior of seeds of selected plant species exposed to a uniform electric field. By changing the intensity of the electric field, the device can be used in the process of cleaning and sorting seeds and other loose materials. The device can be applied to identify differences in the electric charge of the components of loose materials, which can provide a basis for developing new separation techniques.*

***Streszczenie.** W pracy przedstawiono przegląd technik elektroseparacji składników mieszanin nasiennych oraz propozycję urządzenia badawczego do identyfikacji reakcji wybranych gatunków nasion poddanych działaniu jednorodnego pola elektrycznego. Urządzenie może być wykorzystane w wspomaganiu procesów czyszczenia i sortowania mieszanin nasiennych oraz materiałów sypkich, dzięki przewidzianej możliwości zmian wartości natężenia pola elektrycznego. Umożliwia to wyznaczenie różnic w elektryzacji składników mieszanin, co może być podstawą do opracowania nowych technologii separacji. (**Urządzenie badawcze do identyfikacji reakcji wybranych gatunków nasion poddanych działaniu jednorodnego pola elektrycznego**).*

Keywords: electric field, separation of seed mixtures, measuring instrument.
Słowa kluczowe: pole elektryczne, separacja składników mieszanin nasiennych, urządzenie badawcze.

Introduction

Seed quality is an important consideration in seed and food production. The entire production system should be geared towards achieving end products of the highest quality. In many cases, the quality of plant raw materials is determined by the effi-ciency of sorting and separation processes. Fractions with different properties should be effectively separated. Various separation methods are used to separate loose mate-rials based on their physical, aerodynamic, mechanical, and electrical properties or color. New machines and devices for separating components of seed mixtures are be-ing developed, and the existing devices are being improved by focusing on differences in seed attributes, including their electrostatic properties [1-4]. Mixtures of plant seeds are separated based on not only differences in their physical and mechanical proper-ties but also on differences in their biochemical properties [5]. The chemical composi-tion of sorted materials also affects their electrical properties, including electric per-mittivity. An electric field can be used as a supporting method [6-8] to effectively re-move impurities and undesirable components that are difficult to separate from the seed mixture. Some separators rely on the electrical properties of mixture components, and an electric field may be additionally applied to facilitate cleaning and sorting pro-cesses [9-11].

In agricultural production and processing, electric and electromagnetic fields are applied mainly to stimulate plant growth and development [12, 13], and to prolong the shelf life of agricultural products [14, 15]. Seed mixtures can be also cleaned and sorted based on the electrical properties of mixture components [16].

Review of techniques for the electrical separation of seed mixture components

Electrical separation techniques are applied in many industries, including the seed production sector, to separate the components (particles) of loose materials and divide them into fractions. The components of seed mixtures can be separated with the use of an electric field. In many separation devices, mixture components are divided into fractions in an electric field (electrostatic or corona discharge field). Electrical separa-tors can be generally divided into three categories: polarizing, ionizing, and bifilar separators [17].

Polarizing separators polarize the components of the processed mixture and ori-ent them in a given direction by inducing an external electric field. These devices fea-ture a positive and a negative electrode that are separated by a certain distance. In the most popular polarization separators, the positive electrode is a drum which receives the separated mixture from a hopper. The negative electrode consists of several cables that are distributed parallel to the drum's generatrix and are positioned along its cir-cumference. The mixture is separated into fractions under the influence of electro-magnetic, gravitational, and centrifugal forces, as well as the interactions between a charged particle and the drum (the positive electrode). The separated particles behave differently, depending on the sum of the applied forces. The first fraction consists of large, heavy, and moist particles with high electrical conductivity, and these compo-nents are separated first from the positive electrode. The second fraction comprises light and dry particles which adhere to the drum's surface for a longer time. The third fraction is composed of the lightest and driest particles which are removed from the drum with a brush [17].

Ionizing separators rely mainly on the corona discharge effect. The corona effect is an electrical discharge caused by the ionization of gas molecules in the air. The gener-ated stream of electrons and ions creates a negative charge in an ionizing electrostatic separator. Negatively charged particles are attracted to the positive electrode, and they lose their charge upon contact with the electrode. Particles with high electrical conductivity quickly lose their charge, and they fall away from the positive electrode to form the first separated fraction. In turn, particles with low electrical conductivity are transported across a longer distance and are separated into different compart-ments to form successive fractions. Ionizing separators also feature a discharge elec-trode (an additional deflection electrode), and particles are separated based on differ-ences in electrical conductivity, dielectric permittivity, density, and dimensions. An additional deflection electrode is used to increase the number of separated fractions [2, 18].

Bifilar electrostatic separators feature bifilar-wound coils composed of numerous wires with alternating poles. Bifilar coils generate a non-uniform electric field. Parti-cles become polarized when placed in the electric field. Bifilar separators are also known as dielectric separators because particles are sorted into fractions based mainly on their dielectric permittivity. Bifilar separators feature drums or belts [19, 20].

Rationale for the study

According to researchers, electrotechnology applications in the agri-food sector remain insufficiently investigated. The existing knowledge is incomplete and limited to analyzing biophysical changes induced by the stimulation of plant growth and devel-opment, facilitating food processing operations, extending the shelf life of agri-food products, and measuring selected parameters of raw materials and products. The same applies to the use of the electrical properties of seeds in technological operations such as the cleaning and sorting of seed mixtures [21, 22].

A review of the literature indicates that the described seed separation methods and techniques have important practical implications and can be used to design sepa-ration devices and plan separation processes. However, their industrial applications are limited. According to Łuczycka [23], electrotechnology is not widely used in agri-culture, and research into the electrical properties of seeds is scant and does not fully account for the complexity of the problem. Therefore, the present study was under-taken to fill this knowledge gap and provide comprehensive information about varia-tion in the electrical properties of cereal grains grown in Poland. This study was also inspired by an analysis of monographs dedicated to buckwheat [24] and rapeseed cleaning [25]. Konopka [24] investigated whether the kernels of gluten-containing ce-reals (rye, wheat, oats, and barley) can be separated from buckwheat nutlets. In turn, Choszcz [25] demonstrated that the effective separation of cleavers seeds from oilseed rape seeds is problematic. Both cited authors concluded that the analyzed seed mix-tures could not be effectively separated with the use of traditional methods and devic-es (sieves, pneumatic separators, grain graders, or combinations of these devices) due to considerable similarities in seed characteristics (geometric properties, aerodynamic properties, mass).

Meanwhile, raw material purity is one of the most important considerations in seed and food production (including gluten-free products, flour, groats, and rapeseed oil), and this trait can significantly contribute to the advantage of a given raw material over others [26]. It was found that the components of mixtures used as research mate-rials in this study (rye, wheat, barley, oats, buckwheat, oilseed rape, and cleavers) are seeds characterized by different shapes that can be described with the following geo-metric figures: cereal kernels – spheroid, buckwheat – regular tetrahedron, oilseed rape and cleavers – sphere. The seeds of the above plant species also differ in morphology, anatomy, and chemical composition. Therefore, exposure to an electric field can induce variation in their behavior, thus improving separation efficiency and the quality of the processed raw materials [22, 27].

Aim of the study

The aim of this study was to design and build a measuring instrument for ana-lyzing the impact of a uniform electric field on the behavior of rye, wheat, barley, oats, buckwheat, oilseed rape, and cleavers seeds.

Design and structure of the measuring instrument

The instrument for analyzing the behavior of seeds of selected plant species ex-posed to a uniform electric field features two parallel conductive plates which act as electrodes and a power supply system (Fig.1). The top and bottom capacitor plates (4) are poly(methyl methacrylate) (PMMA) plates (2) (external and internal), measuring 150×100×6 mm. In the center, the capacitor plates are separated by brass plates (3) measuring 120×70×0.5 mm. All components were permanently fixed with glue. The capacitor plates were connected to a mains power source with a cable (7) [28].

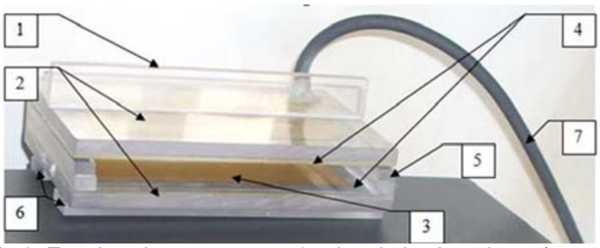

Fig.1. Test bench components: 1 – handgrip, 2 – plates (external and internal), 3 – brass plate, 4 – capacitor plates (electrodes), 5 – distance plate, 6 – supports, 7 – cable connecting the top and bottom capacitor plates with the power supply system [28]

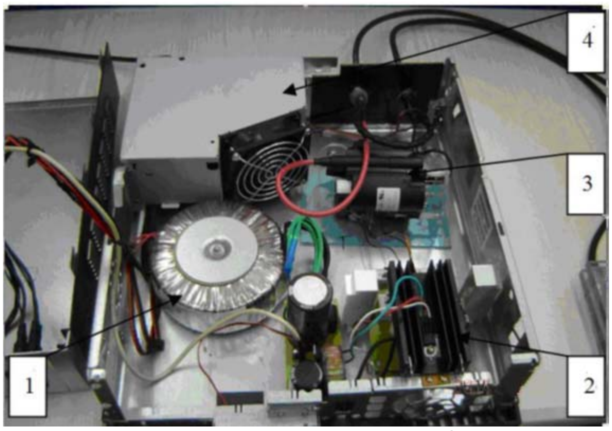

Fig.2. Power supply system: 1 – step down transformer, 2 – voltage converter, 3 – high-voltage transformer, 4 – fan [28]

The negative terminal of the high-voltage cable was connected to the top plate, and the positive terminal of the high-voltage cable was connected to the bottom plate, thus turning both plates into electrodes. Both plates were connected to the power cable with elongated terminals. The top plate is not mechanically connected to the bottom plate. As a result, the top plate can be freely lifted and removed (with the use of a handgrip (1)) to easily manipulate the analyzed objects. The distance between elec-trodes was set with the use of distance plates (5) that were glued on both sides of the bottom plate (width, 17 mm). This parameter was set based on differences in the length of cereal kernels (Konopka, 2006). The distance between electrodes should also enable the user to register the kernels' longitudinal orientation relative to the lines of force in a uniform electric field. Supports (6) were glued to the bottom plate to ensure the in-strument's stability during measurements. Distance plates and supports were also made of PMMA. Brass plates were connected to a high-voltage power source with a voltage control range of 7-19 kV. The main components of the power supply system are presented in Figure 2. The control panel of the power supply system (main compo-nents) is presented in Figure 3 [28].

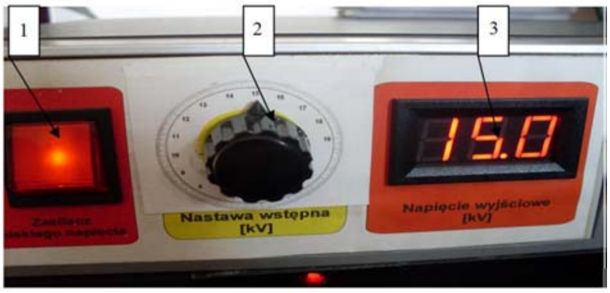

Fig.3. Setting the voltage between the capacitor plates (electrodes) on the external control panel: 1 – power switch, 2 – knob for adjusting initial voltage, 3 – digital panel displaying output voltage [28]

The instrument is connected to mains power and turned on by pressing the main power switch (5) (Fig.4). Alternating current flows to the step down transformer, where the voltage of the incoming current is reduced from 230 V to 12 V. The voltage converter changes the voltage supplied to the primary winding of the high-voltage transformer. The primary winding of the high-voltage transformer is activated by pressing the high-voltage switch (8). The high-voltage transformer is connected to a rectifier, and it transmits high voltage to the electrodes (brass plates) glued in between the capacitor plates (1 and 2). The output voltage supplied to the plates is controlled manually with a knob (6) and displayed on a digital display (7) on the main control panel of the power supply unit (4). The output voltage can be controlled to the nearest 0.1 kV. The power supply system is cooled with a built-in fan. The device has the form of a flat capacitor, and the studied objects are placed in the space between the elec-trodes. When the device is turned on, a uniform electrostatic field with vertical lines of force is generated between the electrodes. The field exerts force on objects placed be-tween the platers. The intensity of the electric field can be modified in the estimated range of 400-1100 kV/m [28].

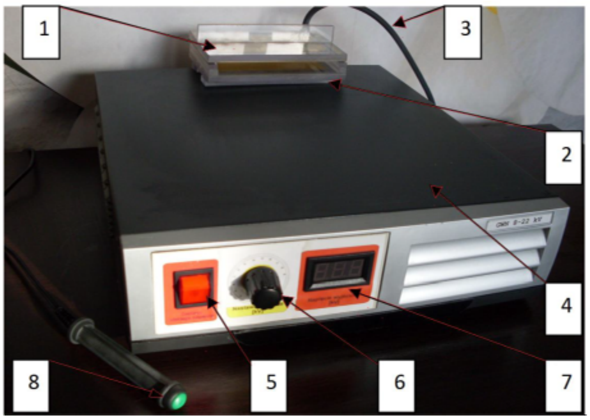

Fig.4. General view of the test bench: 1 – top capacitor plate, 2 – bottom capacitor plate, 3 – cable connecting capacitor plates with the power supply unit, 4 – power sup-ply case, 5 – main power switch, 6 – knob for adjusting initial voltage, 7 – digital panel displaying the output voltage, 8 – high-voltage switch [28]

An additional brass plate (Fig.5) (measuring 150×75×0.5 mm) was connected to ground to remove electrical charges accumulated in the studied objects and to reuse the same objects in successive trials (the seeds of the analyzed plant species were ar-ranged in different configurations between the plates).

Fig.5. Brass plate for removing electric charge during measurements [28]

Conclusions

The proposed instrument for analyzing the behavior of seeds of selected plant species in a uniform electric field can be used in the processes of cleaning and separat-ing seed mixtures to enhance the quality of agricultural raw materials. In the described solution, seeds are separated into fractions based on their electrostatic properties, ra-ther than differences in their anatomical structure, morphology, or chemical composi-tion. The device can minimize changes in the settings of other separation devices (such as the number of sieves with different mesh sizes). The intensity of the electric field (voltage between the plates) can be controlled, and objects with different size and mass can be arranged in various configurations. Therefore, the described approach can be used to separate various types of loose materials.

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REFERENCES

[1] Basiry, M., Esehaghbeygi, A. Cleaning and charging of seeds with an electrostatic separator. *Applied engineering in agriculture*, 28 (2012), No. 1, 143-147
[2] Kovalyshyn, S., Shvets, O., Grundas, S., Tys, J. Use of electro-separation method for improvement of the utility value

of winter rapeseeds, *International Agrophysics*, 27 (2013), No. 4, 419-424
[3] Kovalyshyn, S., Dadak, V., Sokolyk, V., Grundas, S., Stasiak, M., Tys, J. Geometrical and Friction Properties of perennial grasses and their weeds in view of an electro-separation method*, International Agrophysics*, 29 (2015), No. 2, 185-191
[4] Kovalyshyn, S., Dadak, V., Ptashnyk, V., Shvets, O., Łuczycka, D., Dróżdż, T., Kiełbasa, P., Wesołowski, M. The Study of Electrical Properties of Components of a Winter Rape Seed Mixture, *Przegląd Elektrotechniczny*, 1 (2020), 60-64
[5] Kruszelnicka, W., Marczuk, A., Kasner, R., Bałdowska-Witos, P., Piotrowska, K., Flizikowski, J., Tomporowski, A. Mechanical and processing properties of rice grains, *Sustainability*, 12 (2020), No. 2, 552
[6] Fattahi, S. H, Abdollahpour, S., Ghassemzadeh, H., Behfar, H., Mohammadi, S. A. Sunflower's seed separation in high-intensity electric field, *Agricultural Engineering International: CIGR Journal*, 19 (2017), No. 2, 193-199
[7] Fattahi, S. H., Abdollahpour, S., Ghassemzadeh, H., Behfar, H., Mohammadi, S., Mohammdi, S. A. Regression model of sun-flower seed separation and the investigation of its germination in corona field, *Agricultural Engineering International: CIGR Journal*, 19 (2017), No. 2, 187-192
[8] Chabecki, P., Bordun, I., Ivashchyshyn, F. Highly dispersed carbon powder separation by triboelectric method, *Przegląd Elektrotechniczny*, 95 (2019), No. 1,81-84
[9] Li, F., Zhang, X., Li, X., Wang, H. Effects electric field processing and dielectric separation on cotton seed germination rate and seedling mass, *Transactions of the Chinese Society of Agricultural Engineering*, 26 (2013), No. 9, 128-132
[10] Xu, J., Tan, M., Zhang, C., Li, F. Improving paddy seed vigor by corona discharge field processing and dielectric separation, *Transactions of the Chinese Society of Agricultural Engineering* 29 (2013), No. 23, 233-240
[11] Ciobanu, V., Visan, A., Paun, G. 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, (2017), May 24-26, 1000-1005
[12] Binsfeld, J., Barbieri, A., Huth, C., Cabrera, I., Henning, L. Use of bioactivator, biostimulant and complex of nutrients in soybean seeds, *Pesqui. Agropecu. Trop*. 44 (2014), No. 1, 88-94
[13] Azeredo, G., Paula, R., Valeri, S. Electrical conductivity in Piptadenia moniliformis benth. Seed lots classified by size and color, *Revista Árvore,* 40 (2016), No. 5, 855-866
[14] Cieśla, A. (). Field distribution in separator's working space for various winding configuration. *Przegląd Elektrotechniczny*, 87 (2011), No. 7, 99-103
[15] Cieśla, A., Syrek, P. Parameters and position of the applicator's effect on magnetic field distribution during magnetotherapy. *Przegląd Elektrotechniczny*, 88 (2012), No. 12b, 124-127
[16] Kovalyshyn, S., Ptashnyk, V., Shvets, O., Ivashchyshyn, F., Nester, B., Kasner, R., Urbańska, P. The separation assessment of small-seeded mixtures of agricultural crops. *In Journal of Physics: Conference Series*, 1781 (2021), No. 1, p. 012020). IOP Publishing
[17] Marks N., Maszyny do czyszczenia i sortowania płodów rolnych, Wydawnictwo Uniwersytetu Rolniczego w Krakowie, Kraków, (2012)
[18] Skowron, M., Syrek, P., Surowiak, A. The application of the electrodynamic separator in minerals beneficiation, *In IOP Conf. Ser.: Mater. Sci. Eng.*, 200 (2017), No. 1, p. 012017. IOP Publishing
[19] Pietrzyk, W., Horyński, M., Sumorek, A., Ścibisz, M., Walusiak, S., Grundas S., Uzwojenia bifilarne do odpylania w przemyśle rolno-spożywczym, *Acta Agrophysica PAN*, 43 (2001), Lublin, Monograph, 90 pp. ISBN 83-87385-61-3
[20] Kuna-Broniewski, M. Elektrostatyczny separator bifilarny, patent, Pl 226223 B1, (2016), February 29, 2016 (30.06.2017)
[21] Pietruszewski, S., Wpływ pól magnetycznych i elektrycznych na kiełkowanie nasion wybranych roślin uprawnych, *Technica Agraria*, 1 (2002), No. 1, 75-81
[22] Pietrzyk, W. Standaryzacja badań wpływu pól elektromagnetycznych na materiały pochodzenia biologicznego, *Acta Agrophysica*, 8 (2006), No. 4, 915-921
[23] Łuczycka, D. Cechy elektryczne ziaren pszenicy, Wydawnictwo Uniwersytetu Przyrodniczego we Wrocławiu, Wrocław. (2009)
[24] Konopka, S. Analiza procesu separacji nasion gryki przy wykorzystaniu prętowych powierzchni roboczych tryjerów. *Inżynieria Rolnicza*, 8 (2006), No. 83, Habilitation theses. No. 21. ISSN 1429-7264
[25] Choszcz, D. J. Efektywność rozdzielania mieszaniny nasion rzepaku i przytulii czepnej w separatorze taśma pętelkową, Habilitation thesis, *Inżynieria Rolnicza*, (2009), Kraków
[26] Aladjadjiyan, A., Physical Factors for Plant Growth Stimulation Improve Food Quality, *Food Prod. Approaches, Challenges Tasks*. (2012)
[27] Majcher, J., Szwed, G., Segregacja szczególnie trudnych do rozdzielenia grup roślin przy pomocy pola elektrostatycznego, Prace Instytutu Elektrotechniki, 251 (2011), 21-29
[28] Urbańska-Gizińska, R. Identyfikacja przestrzennej orientacji nasion w jednorodnym polu elektrycznym w aspekcie wykorzystania w procesach separacji (Identification of the spatial orientation of seeds in a homogeneous electric field from the aspect of its use in separation processes). Ph.D. Thesis, Uniwersytet Warmińsko-Mazurki w Olsztynie, Wydział Nauk Technicznych, Olsztyn, Poland, (2018)