

Promising Directions for Sorting Seeds of Various Crops: Improving Electric Field Methods and Integrating Them with Modern Sensor Technologies

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АННОТАЦИЯ:

Improving the germination capacity, purity, and uniformity of seed lots is a key task in seed production, yet pneumatic and mechanical sorting rely on only one or two physical traits, mass or size. This article reviews electric field sorting of agricultural seeds as an alternative that acts on several properties at once: mass, shape, density, electrical resistance, and dielectric permittivity. Published studies show that corona-discharge separation can improve seed purity and raise barley germination by 17.34%, and that an electrostatic separator can remove plastic film residue from seed cotton at up to 96.8% efficiency. Analysis of existing devices identifies a main limitation: electrode geometry is not matched to seed shape. To address this, a universal sorting device is proposed, with a polyethylene working body carrying screw-shaped channels and oppositely charged electrodes of triangular cross-section. Further directions are outlined: a hybrid electro-optical system combining electric field sorting with NIR/AI sensing, adaptive voltage control based on seed moisture, application to cotton seed cleaning, and sensor-based energy management. The proposed device and these directions are conceptual and still need experimental and numerical validation, for example by finite element modeling of the electric field.

Introduction. Improving the quality indicators of agricultural crop seeds, that is, ensuring the germination capacity, purity, and uniformity of planting material, remains one of the most pressing tasks in seed production. Traditional seed sorting methods, namely pneumatic (air-flow-based) and mechanical (sieving, size grading) methods, rely mainly on one or two physical characteristics of the seeds, i.e., their mass or size. This makes it difficult to separate seeds of similar mass and size that nevertheless differ in quality (for example, diseased, immature, or genetically foreign seeds).

Electric field sorting technology is recognized as an alternative way to solve this problem, because the electric field acts selectively on seeds according to several of their physico-mechanical and electrophysical properties at once: mass, geometric shape, density, electrical resistance, and dielectric permittivity. Foreign studies confirm this: sorting wheat, barley, and canola seeds in a corona-discharge electrostatic separator has been found to have a significant effect ($P < 0.05$) on purity and 1000-seed weight, and to increase the germination of barley seeds by 17.34 percent.[1] Studies on sorting sunflower seeds in a high-intensity electric field have likewise shown that electric forces effectively separate seed fractions.[2]

Scientific and Theoretical Foundations of Electric Field Sorting

The physical essence of electrostatic sorting is that seeds are charged by corona discharge or by induction, after which the force of the electric field acts on them; depending on charge density and shape characteristics, different seeds move along different trajectories and are thereby separated from one another.[3] This approach has been shown to be effective, in particular, for separating broken seeds from whole ones, because broken seeds have a relatively smaller surface area, acquire less charge, and accordingly move along a different trajectory.[3]

At the same time, the effect of the electric field on seeds is not limited to mechanical sorting. A number of studies have noted that the electric field also changes the physiological state of seeds, in particular improving the speed and uniformity of germination,[1] which makes it possible to regard electric sorting devices not only as sorting equipment but also as equipment for preparing (stimulating) seeds for sowing.

Critical Analysis of Existing Solutions

At present, the following have been proposed for sorting agricultural crop seeds in an electric field: chamber-type and drum-type corona electroseparators, dielectric devices, and devices with an electric field formed between parabolic and ring-shaped electrodes. Similar approaches are used in international practice as well: for example, in a laboratory device called ELSEP, the effectiveness of separating seeds of wheat, barley, oat, wild oat, and wild weed species using roll-type and free-fall separators has been demonstrated.[4]

However, most of these devices are adapted to a specific seed type or pair of fractions, and their electrode geometry does not take into account the different shape characteristics of seeds (round, elongated, flat, etc.). In our opinion, precisely this aspect, the fact that electrode shape is not adapted to seed geometry, is the most serious limitation of existing devices, because at

the same voltage and field density, seeds of different shapes are charged unevenly and sorting accuracy decreases.

The Proposed Universal Device with Triangular-Section Electrodes

Based on the above analysis, we put forward the idea of improving the working body of the electric sorting device: arranging the electrodes of different polarity, which are wound onto its surface, in a triangular cross-section shape that takes the shape of the seeds into account. The device consists of a working body made from a polyethylene pipe, two-start screw-shaped channels cut into it, and sharp triangular electrodes wound into those channels. Seeds fed from the loading hopper through the feeder and an inclined board onto the surface of the working body as a uniform layer settle between the electrodes, become polarized under the influence of the induced electric field and the electric field between the electrodes, and are attracted to the surface of the working body by the total electric force. Balanced against centrifugal force, gravity, friction, and reaction forces, seeds with different physico-mechanical properties detach at different rotation angles during rotational motion and fall into the corresponding compartments of the receiving hopper, that is, into the sowing and technical fractions.

In our view, the triangular cross-section of the electrodes sharply increases the density of the field lines at the electrode tip, which makes it possible to achieve a high degree of polarization even at relatively low voltage and thereby to reduce energy consumption. To confirm this hypothesis quantitatively, we recommend that future research model the relationship between electrode tip radius and electric field strength using the finite element method (FEM).

New Ideas and Directions for Development

1. A hybrid electro-optical sorting system. In modern seed production, optical sorting technologies, namely RGB, near-infrared (NIR), and hyperspectral cameras together with artificial intelligence algorithms, are already widely used, and they can detect differences in seed color, shape, and even internal defects with high accuracy.[5] In particular, systems based on lightweight convolutional neural networks have been shown to provide high speed and accuracy in classifying seeds in real time.[6] In our opinion, it is advisable to combine the proposed triangular-electrode device with an optical/NIR sensor in a single technological line: the electric field carries out preliminary, coarse sorting by physico-mechanical properties (mass, density, electrical resistance), and then the optical-AI unit performs fine sorting (color, external defects, breakage). Such a hybrid approach makes it possible to achieve higher overall accuracy than using either method alone, because two independent physical principles complement each other.

2. Adaptive voltage control (a feedback system). In current devices, the voltage supplied to the electrodes is usually constant and preset. We propose installing a sensor that measures the moisture and density of the seed flow in real time and introducing an adaptive control system that automatically adjusts the voltage of the high-voltage power supply based on the

data obtained. The basis for this is that the efficiency of electrostatic separators is highly sensitive to moisture: for example, the optimal moisture for wheat and barley was only about 6-7 percent, and at higher moisture content almost no separation occurred.[1] Therefore, under moisture conditions that vary by season and by batch, a static voltage regime does not give stable results, whereas adaptive control automatically selects the optimal regime for each batch.

3. Expanding application to cotton growing. Given that cotton is the leading crop in Uzbekistan's agriculture, adapting the proposed universal device to the tasks of cleaning cottonseed and separating it from fragments of plastic film is of particular practical importance. In a study carried out in China, it was reported that with the optimal parameters of a mesh-type roller electrostatic separator (charging time of 2.71 seconds, separation voltage of -30 kV, and electrode plate spacing of 14.75 cm), the efficiency of separating film residue from seed cotton reached 96.8 percent.[7] This figure confirms that, with correctly chosen geometric and electrical parameters, the electric sorting method can give high results even in cleaning machine-picked raw cotton, which broadens the field of application of the proposed triangular-electrode device.

4. Energy efficiency and sustainability. The energy consumption of high-voltage devices is an important economic factor in introducing them into production. Therefore, alongside optimizing electrode shape (triangular cross-section), we recommend introducing a sensor-based energy management unit that activates the voltage source only when a seed flow is present. In our estimation, this could significantly reduce energy consumption and ensure long-term, continuous operation of the device.

Conclusion

The analysis carried out shows that sorting agricultural crop seeds in an electric field has a number of scientifically grounded advantages over traditional pneumatic and mechanical methods. The idea of arranging the electrodes wound onto the surface of the working body in a triangular cross-section that takes seed geometry into account expands the functional capabilities of the device and allows it to be used as a universal device. At the same time, for the further development of this direction, hybridizing electric sorting with modern optical-AI sensor technologies, adaptive voltage control, and improving energy efficiency are identified as promising research directions. These approaches may be of practical importance, especially for grain and cotton seed production in the conditions of Uzbekistan.

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