Sunflower's seed separation in high-intensity electric field

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Abstract: Seed separation and cleaning is one of the important processes in obtaining pure high quality seed. The separation can be carried out by the properties of physical, electrical, magnetic, optical, etc. In this study, a high tension roll-type electrostatic separator was constructed to separate sunflower's seed in order to extract pure seed and remove impurities. An extended corona discharge field was generated by three wire type electrodes in the roll-type separator. The experiment was performed in the form of factorial analysis based on a randomized complete block design with three replications. The effects of the roll rotational speed, the electrode distance from the roll and the amount of power supply as effective factors in separation were examined on sunflower and material other than grain. The pure sunflower's seed was measured in the treatment combinations of the rotational speed (40, 50 and 60 rpm), electrode distance from roll (4, 5 and 6 cm) and the power supply voltage (20, 30 and 40 kV). Results of the compare means showed that the factors of rotational speed and electrode distance from roll had positive effect on the purity of sunflower's seed, but the effect of power supply voltage was negative. Maximum separation occurred at in the treatment combination 60 rpm, 6 cm and 20 kV.

Keywords: seed purity, corona discharge, electrostatic separation, sunflower

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1 Introduction

Sunflower (*Helianthus annuus L.*) seed is one of the most important oilseed crops due to its highly nutritious oil, and large quantity in a unit volume (Shukla et al., 1992). Agriculture is the largest single industry in the world, and seed production is an important segment of this industry. Seed, as it comes from the field, contains various contaminants like weed seeds, other crop seeds, and such inert material as stems, leaves, broken seed, and dirt. These contaminants must be removed, and the clean seed properly handled and stored to provide a high quality planting seed that will increase farm production (Harmond et al., 1968).

The main characteristics that influence the ability to separation seeds are seed size (length, width, and thickness), shape, density, surface texture, terminal velocity, resilience, color, and electrical conductivity. Many types of seed-cleaning machines are available that exploit the above physical properties of seeds, either individually or in some combination (Harmond et al., 1968). The whole complex of the electrical and mechanical characteristics of the seeds should be used in order to separate effectively undesirable seeds (Požėlienė, 2001). Electric separators could be used at the finishing stage of the cleaning (Kazimirchuk and Xziretdinov, 1995; Požėlienė and Lynikienė, 1998). Electrostatic separation is a generic term given to a significant class of material processing technologies commonly used for the sorting of granular mixtures by means of electrical forces acting on charged or polarized particles (Tilmatine et al., 2009).

Electrostatic separation is based on differences in the ability of particles to develop and maintain electric charges. There are various techniques that can be used for charging particles. These include conductive induction,

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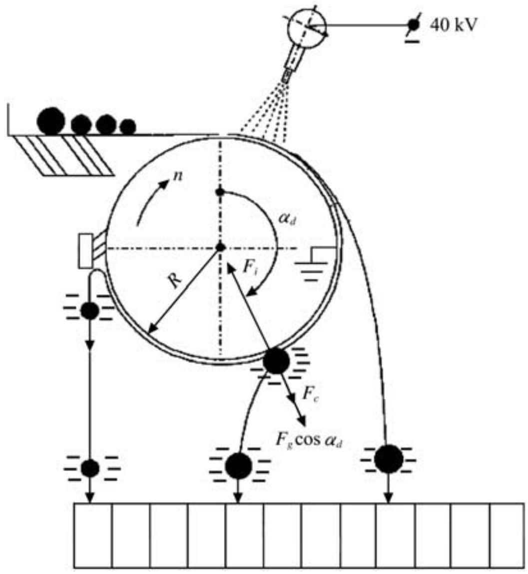
ion bombardment, and triboelectrification (Knoll and Taylor, 1984). There are three clean electrostatic processes for granular material separation such as 1) role-type electrostatic separator, 2) plate-type electrostatic separator and free-fall electrostatic separator (Tilmatine et al., 2009). Besides the configuration of the electrode system that generates the corona discharge and determines the electric field forces acting on the particles, several other physical factors influence the efficiency of the separation process including roll speed, feed rate and ambient conditions. Their optimum values are related to the characteristics of the feed materials: nature, composition, size and shape of the granules, etc. (Iuga et al., 2001).

The particles to be sorted are deposited by a vibratory feeder onto the surface of a grounded rotating roll electrode, which introduces them in a zone of intense electric field created by one or several high voltage electrodes. One of the electrodes creates a corona discharge, so that all the particles are charged by ion bombardment. The insulating particles adhere to the surface of the roll electrode under the effect of the electric image force, while the conducting ones are neutralized, then charged at opposite polarity by electrostatic induction and projected towards the static electrode of opposite polarity (Dascalescu et al., 1998). Forces acting on insulating particles (nonconductive particles) in roll-type corona-electrostatic separators are the electric image force (F_i), centrifugal force (F_c) and the gravitational force (F_g) (Figure 1). Particles detach from the rotating electrode (roll) when the resultant of gravitational and centrifugal forces surpasses the pinning action of the electric image force (Younes et al., 2013).

The force existing between two charged particles (image force) would be computed using the following equation (Dascalescu et al., 1995).

$$F_i = \frac{1}{4\pi\varepsilon_0}\frac{qq'}{r^2} \tag{1}$$

where, q and q' are the particle charge and r is the distance between the two particles. ε_0 is called the dielectric constant or absolute permittivity, which specifies the property of the environment and its amount in the air equals to the following equation.



Notes: Nonconductive particles affected by the image force (F_i), centrifugal force (F_c) and component of weight ($F_g\cos\alpha_d$) with the detachment angle of α_d for each particle (Iuga et al., 2001; Younes et al., 2013).

Figure 1 The electrostatic separator by the negative corona discharge

$$\varepsilon_0 = 8.854\times10^{-12}\frac{C^2}{N\cdot m^2} \tag{2}$$

Dielectric constant indicates the ability of a material to store energy from the electrostatic field.

The first commercial electrostatic separator was developed by Osborne in 1880. It is interesting to note that Osborne's machine was made specifically for processing an agricultural commodity. The function of this machine was to remove chaff and other lightweight material which reduced the quality of flour. The contaminating material was attracted or "lifted" out of the flour by a charged, hard-rubber roll. The electric charge was produced in this machine, as it was in most early electrostatic separators, by friction (Harmond et al., 1961). Krishnan et al. (1985) made a belt-type electrostatic separator to remove flower parts from onion seeds. The best result was achieved at a voltage of 17 kV and conveyor belt speed of 0.2 m s^{-1}. Leonov (1984) designed a rotary drum seed electrostatic separator using a polyvinyl chloride (PVC) drum. The PVC drum rotated at 32 rpm and a voltage of 5 kV was applied.

In this paper, the effects of roll rotational speed, corona electrode distance from roll and direct current (DC) power supply voltage are investigated on sunflower seed separation for achieve pure sunflower seeds. The tests are carried out as the experimental design (the analysis of variance).

2 Material and methods

2.1 Separator construction

A roll type corona electrostatic separator was constructed for separate sunflower seeds (Figure 2). In this separator, to produce the corona field for sunflower charging three wire-type electrodes was used. Corona electrodes were connected a high voltage power supply with a maximum output voltage of 40 kV, DC at 3 mA. Diameter of roll was 50 cm. The three corona electrodes were placed on roll with angle of 30, 50 and 70 degrees.

Figure 2 Photography of a used laboratory roll-type corona separator

The sunflower mixture to be sorted are deposited by a vibratory feeder onto the surface of a grounded rotating roll electrode, which introduces them in a zone of intense electric field created by three high voltage electrodes. Three of the electrodes create a corona discharge, so that all the mixture of pure sunflower seeds (the big size of sunflower seeds that are used for the next planting season in field) and material other than grain (MOG, includes the medium and small sizes of sunflower seeds, leaves, broken and empty seeds, ray flowers and etc.,) are charged by ion bombardment. The mixture of pure sunflower seeds and MOG adhere to the surface of the roll electrode under the effect of the electric image force. In the following, the pure sunflower seeds and MOG will have the different detachment trajectory from the rotary roll. The reason for different trajectory of sunflower is the action of image force, centrifugal force and gravitational force. A nine-compartment bin was placed under the rotary roll into which the seeds fell from the roll. Each bin was in dimension 9×18 cm. Finally, some of the charged pure sunflower seeds and MOG always adhere on roll and was removed by the brush.

2.2 Sampling preparation

In this study, the hybrid variety of sunflower was used for the separation investigation. Mixture of pure sunflower seeds and MOG were in the storage moisture of 9%-10%. Initially that the pure sunflower seed separate from MOG manually (Figure 3). 12 g of pure sunflower seed and 50 g of MOG were mixed each other as the test sample.

Figure 3 Pure sunflower seed (left) and MOG (right)

2.3 Experimental design

The sample weights in the first bin (the first bin on the right) under roll rotary was investigated for the expression of sunflower separation. The weight of the pure sunflower seeds were recorded by using a digital balance (Model Adam, accuracy 0.01 g). Initially, the levels of factors (rotational speed, electrode distance and the amount of power supply voltage) were determined with the primary sampling. Experiments at three rotational speed levels (40, 50, and 60 rpm), three electrode distance levels (4, 5 and 6 cm) and three amount of power supply voltage (20, 30 and 40 kV) were conducted in the form of factorial analysis based on a randomized complete block design with three replications. SPSS21 and MSTATC software was used to obtain the analysis of variance and comparison of means.

3 Results and discussion

12 g pure sunflower seeds and 50 g of MOG (sum of

the pure sunflower seeds and MOG were 62 g) are deposited (mixture slightly distanced from one another) to be separated by a vibratory feeder onto the surface of a grounded rotating roll electrode. The charge acquired by the insulating particles depends on their density on the surface of the carrier electrode (roll). The feed rate should be chosen such that the material to form a uniform monolayer on the surface of the roll electrode (Urs et al., 2004). The mixture is charged by ion bombardment with corona discharge of three wire-type electrodes. Then the mixture is collected in bins under the rotary roll. The separation data is achieved with the weighting of sample in the first bin. The ideal separation is achieved when that the weight of sample be equal to 12 g in the first bin.

To study the effect of selected independent variables on the separation of pure sunflower seeds, statistical analysis was performed on the data. Evaluation of Kolmogorov-Smirnov test in SPSS21 software showed that the data (weight of the pure sunflower seeds in the first bin) were not normal. So, the square root transformation method was used for normalization of data. Then the data for analysis were entered into MSTATC software in form of factorial analysis based on a randomized complete block design with three replications. The results of variance analysis for the effects of replication (*R*), electrode distance from roll (*D*), roll rotational speed (*N*) and power supply voltage (*V*) on sunflower seed separation are given in Table 1.

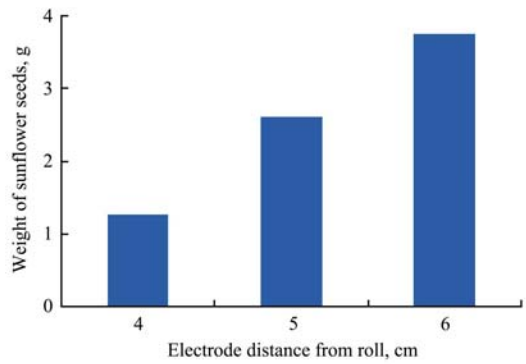
Table 1 Variance analysis of effective factors on the pure sunflower seed

Source of variation	Degree of freedom	Sum of square	Mean of square
R	2	0.019	0.010
D	2	8.970	4.485*
N	2	19.579	9.789*
*D*N*	4	1.183	0.296*
V	2	3.819	1.910*
*D*V*	4	1.038	0.260*
*N*V*	4	0.530	0.132*
*D*N*V*	8	0.491	0.061*
Experimental error	52	0.278	0.005
Total	80	35.908	-

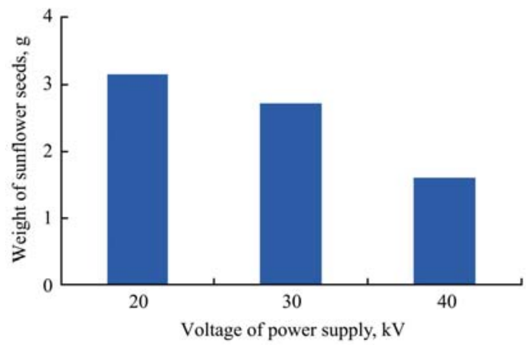
Note: '*' represent significance at the 5% level.

Results of analysis of variance showed that the main effects of the experimental factors had a significant effect on the sunflower seed separation in 5% probability level. The results of the variance analysis in Table 1 show that *R* was not significant and it can be concluded that the experiment replications were carried out in the same condition.

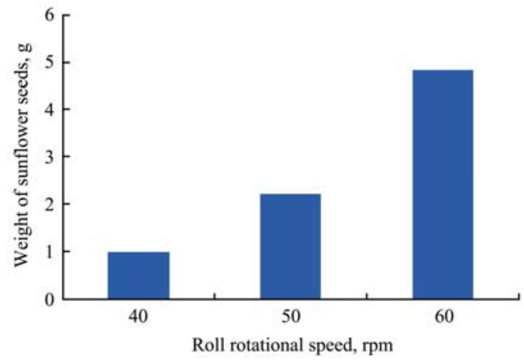
Based on analyses of variance (Table 1), the reaction effect of three factor (roll rotational speed, electrode distance from roll and power supply voltage) was significant in 5% probability level. So the reaction effect was investigated. The investigation of data showed that experimental factors don't have reaction effect and the factors influence the weight of sunflower seed separately. It means that the data of sunflower seed (in the first bin) changes in value statically. So, main effect of the roll rotational speed, electrode distance from roll and power supply voltage must be studied. The results are given in Figure 4.



a. Roll rotational speed



b. Electrode distance from roll



c. On the sunflower seed separation

Figure 4 The effect of voltage of power supply

According to mean comparison of main effect (Figure 4), between three levels of electrode distance from roll, roll rotational speed and power supply voltage significant differences were found on the sunflower seed separation in 5% probability level. Amount of sunflower seed increased from 4 to 6 cm in the first bin and the distance of 6 cm has the highest separation efficiency (Figure 4a). A given seed tends to hold or lose charge according to its electrical conductivity (Harmond et al., 1961). The better conductors of a seed mixture will lose their charge and fall in a normal discharge pattern from the belt. Seeds that are relatively poor conductors will adhere to the belt, as shown, until their charge is neutralized (Harmond et al., 1961). The sunflower seed is similar to insulators (non-conductive). As the seeds are non-conductive granules, they slowly lose the accumulated charge (Butunoi et al., 2011). Three important forces act on the charged seed: the electric image force, determining a pinning effect on the roll surface, gravitational force, and centrifugal force, both producing a detachment effect. The seeds trajectories depend on the resulting force F (the sum of gravity, centrifugal and image forces) and are influenced by mass, shape, dimension and surface conductivity of seeds (Butunoi et al., 2011). For a given voltage, a strong electric field is produced in the close discharge gaps between corona wire electrode and the surface of rotating roll electrode than the further discharge gaps (Samuila et al., 1997). Consequently, the amount of surface charge and image force (caused by ion bombardment) is increased with crossing of sunflower seed from the electric field zone. So, the pure seeds and MOG adhere on roll firmly in the distance of 4 cm and don't drop in the first bin.

According to mean comparisons for power supply voltage (Figure 4), the suitable conditions for sunflower seed separation were a voltage of 20 kV, which lead to the maximum seeds weight of the first bin. The separation decreased from 20 to 40 kV (Figure 4b). Investigation of charge Q in insulating spheres (radius: 1.5 mm) on the surface of a rotating roll electrode affected by an ionizing field E showed that the higher voltages produced more charge on surface (Samuila et al., 1997). In the voltage of 40 kV, image force is increasing because of the local field intensity (ion bombardment) becomes even stronger. So, the rapid detachment effect of the gravitational and centrifugal forces decreases. In other words, the image force is higher than the sum of gravitational and centrifugal forces.

Also, the separation increased from 40 to 60 rpm and the rotational speed of 60 rpm has the highest separation (Figure 4c). The centrifugal force increases with increasing of speed. So, the big sunflower seed separate from roll electrode surface because of the high mass density. Also in the higher speed, the surface charge of seeds reduces and subsequently the image force decreases in a given voltage (Samuila et al., 1997).

Due to the big size of pure sunflower seed, moister percent increases (higher volume and mass density). It can be concluded that the conductivity, dielectric constant and loss tangent of sunflower achenes increase when the moisture content of samples increases, and dielectric constant and loss tangent decrease as the frequency of electric field increases (Novák and Vitázek, 2014). The image force decreases with increasing dielectric constant and the big seeds drop from the roll like the conductive material and leaves, empty seeds and ray flowers fall in the subsequent bins because of the lower moisture percent. Higher moisture content caused higher electric conductivity of the seeds. This caused the seeds, like a conductive particle, to transfer their charges to the belt and become neutralized (Horynski, 2001). Požėlienė et al. (2008) stated that separation could improve by changing the belt material. Increasing the moisture of buckwheat seeds decreased their detachment angle (Požėlienė et al, 2008). Seeds and particles that are relatively poor conductors, like straws, adhered to the belt lost their charges gradually and fell into the subsequent bins compartments (Lundahl, 2001).

Seed sunflower separation was observed in the best treatment combination 60 rpm, 6 cm and 20 kV. Also, the worst separation happened in treatment combination 40 rpm, 4 cm and 40 kV. Obviously, the Figure 5 shows this phenomenon. Specifically, the cleaning of pure sunflower seed from leaves and ray flowers carried out in the whole of treatment. Very few seeds with medium size dropped in the first bin.

Notes: The best treatment combination 60 rpm, 6 cm and 20 kV (above) and the worst treatment combination 40 rpm, 4 cm and 40 kV (down).

Figure 5 The results of Sunflower seed separation in the electrostatic separator with three wire-type electrodes

4 Conclusions

Seed size (length, width, and thickness), shape, density, surface texture, terminal velocity, resilience, color, and electrical conductivity influence the ability of seeds separation. In this paper, electrical properties of sunflower seeds were used for the separation. The electrostatic separator with three wire-type electrodes developed in this paper was able to separate a pure sunflower seeds from MOG. The pure sunflower seeds weight of first bin in the treatment combination 20 kV, 6 cm and 60 rpm was the maximum amount. The results of this paper were acceptable. As well as separation, the cleaning of sunflower seeds are carried out by the electrostatic separator and the leaves, empty seeds and ray flowers of sunflower don't dropped in the first bin. The whole complex of the electrical and mechanical characteristics of the seeds should be used in order to ideal separation of sunflower seeds.

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