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DESIGN CONCEPT AND PARAMETERS OF A CONICAL BAR SEPARATOR

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Abstract

The process of adapting a screen separator to seeds of a given species and variety requires a corresponding set of replaceable screens. Screen replacement is a time-consuming process. Screens are often selected from the available size range, therefore, cleaning and separation processes are not always optimized. This study proposes a design concept of a new device for cleaning and separating seeds, which features a conical bar screen that rotates around its own axis. The screen has grooves whose width is smallest at the beginning of the screen and increases along the screen surface. Seeds can be sorted into various size fractions by changing the position of collecting buckets under the screen. The functional parameters of the separating device were designed based on a review of publications describing the size of the most popular agricultural seeds. The basic geometrical relationships in the proposed conical bar screen were described. The geometrical parameters of the screen were selected on the assumption that the radius at which bars are fixed to the screen can range from 200 mm to 400 mm and that bar diameter can range from 5 mm to 10 mm. Two variants of the device were proposed as a replacement for one universal separating screen. The first variant will be used to sort small seeds, including seeds of small-seeded legumes, seeds of major cereal species and medium-sized seeds with dimensions similar to cereal seeds, whereas the second variant will be applied to separate large seeds, including seeds of large-seeded legumes and plumper seeds from the medium-size fraction. The width of grooves at the beginning and end of the screen should equal 1 mm and 5 mm in the first variant and 2.5 mm and 13 mm in the second variant, respectively.

Symbols:
CV – coefficient of variation of a trait [%],
d – bar diameter [mm],
L – length of bar screen [mm],
n – number of grooves in the screen,

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r_1 – bar spacing at the beginning of the screen [mm],
r_2 – bar spacing at the end of the screen [mm],
R_1 – radius at which bars are fixed to clamp rings at the beginning of the screen [mm],
R_2 – radius at which bars are fixed to clamp rings at the end of the screen [mm],
s – groove width at distance x from the beginning of the screen [mm],
s_1 – groove width at the beginning of the screen [mm],
s_2 – groove width at the end of the screen [mm],
SD – standard deviation of seed thickness [mm],
x – distance from the beginning of the screen [mm],
β – base angle of a conical screen [degrees],
γ – opening angle of a conical screen [degrees].

Introduction

Seed mixtures are most often cleaned and sorted with the use of pneumatic and screen separators on account of their high efficiency (GROCHOWICZ 1994). Every screen separator is equipped with a collecting bucket and a set of mostly flat screens. Screens have openings that are formed through the appropriate arrangement of wires or perforations in sheet metal. The shape and size of openings is designed based on the separator's efficiency and the species of separated seeds. The openings in every screen have identical geometry and dimensions. The seeds are separated into two fractions: the fraction that is retained by the screen (retained fraction) and the fraction that passes through the screen (sifted fraction). The screens installed in collecting buckets are set at an angle to ensure that the retained fraction is set into motion by a moving bucket and to guarantee the continuity of the sorting process.

Most separators are equipped with a set of screens. Screens are replaced to account for the parameters of different seed species or same-species batches with various seed plumpness. This laborious process has prompted researchers to design new devices where the seed separation process, regardless of crop species, would not require time-consuming modifications. One of such solutions involves a string sieve where strings are stretched between horizontal bars (KALINIEWICZ 2013b, 2015). At the beginning of the screen, strings are attached to a bar in a single row at equal distances, and at the end of the screen, strings are attached to at least one bar, where one string is placed under another to create grooves whose width increases with the distance from the beginning of the screen. Seeds are sorted into various size fractions by changing the position of collecting buckets under the string sieve. A theoretical analysis of the sorting process (KALINIEWICZ 2013a) revealed that seeds are propelled into motion when the string sieve is positioned at an estimated angle of 45^{o}, and to ensure the continuity of the sorting process, the string sieve should be set at an angle of around 50^{o}. The choice of such a large inclination angle leads to an excessive increase in the dimensions of the screen separator, in particular height, and lowers separation efficiency. To avoid the above scenario, the inclination angle of a string sieve should not exceed 10°, and seeds should be propelled into motion by a moving collecting bucket (KALINIEWICZ, DOMAŃSKI 2013). In the analyzed case, the angular velocity of the transmission shaft has to be higher than the speed of conventional collecting buckets because at lower angular velocity, seeds will be wedged in grooves, thus clogging the screen. Due to the numerous disadvantages of such separators, the solution proposed in this study was based on a conical bar separator (JADWISIEŃCZAK et al. 2016).

The aim of this study was to analyze the structure and geometrical parameters of a conical bar separator, and to determine whether it can be adjusted to clean and separate seeds of basic crop species.

Materials and Methods

In the present experiment, the parameters of a conical bar separator were selected based on geometrical relationships between the separator's working elements and the physical properties of seeds. This study is constitutes the first stage of comprehensive research investigating the conical separator. The next stages of research will include the development of a mathematical model of the seed separation process carried out with the use of the proposed separator, and experimental verification and validation of the model. Our findings will be discussed in separate articles.

The following assumptions were made in the initial stages of designing a conical separator:

– the separator is to replace a conventional screen separator for cleaning and sorting agricultural seeds, equipped with replaceable screens with longitudinal openings,

– the working element of the proposed separator is the inner surface of a truncated cone with grooves along the perimeter. Groove width increases towards the end of the screen,

– the screen is positioned at a small angle to move seeds towards the end of the screen when it is set in rotary motion,

– the screen is composed of bars with identical diameter, permanently attached to two clamp rings (Fig. 1) with a smaller diameter at the inlet and a larger diameter at the outlet,

– groove width at the beginning of the screen is smaller than the thickness of the smallest seeds of the principal species, and groove width at the end of the screen is larger than the thickness of the largest seeds of the principal species,

– the screen can be formed by bars which have different sections (circular, square, triangular, hexagonal, etc.) and are made of various materials,

– collecting buckets for different seed fractions are positioned under the screen.

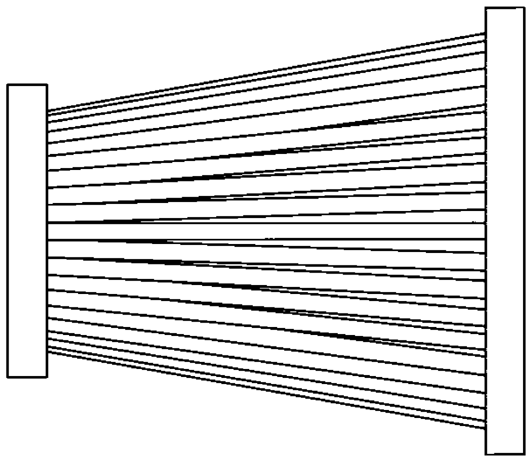

Fig. 1. View of a conical bar screen

Results and Discussion

Geometrical relationships in a bar screen

The screen will be composed of cylindrical bars with diameter d (Fig. 2). Bars will be fixed to clamp rings at equal distances, and the size of the resulting grooves will change from s_1 to s_2 between the beginning and end of the screen. Bar spacing at the beginning and end of the screen can be calculated with the use of the below formulas:

$$r_1 = s_1 + d \tag{1}$$

$$r_2 = s_2 + d \tag{2}$$

The following relationships can be derived based on the n number of grooves along the screen perimeter:

$$2 \cdot \pi \cdot R_1 = n \cdot r_1 \tag{3}$$

$$2 \cdot \pi \cdot R_2 = n \cdot r_2 \tag{4}$$

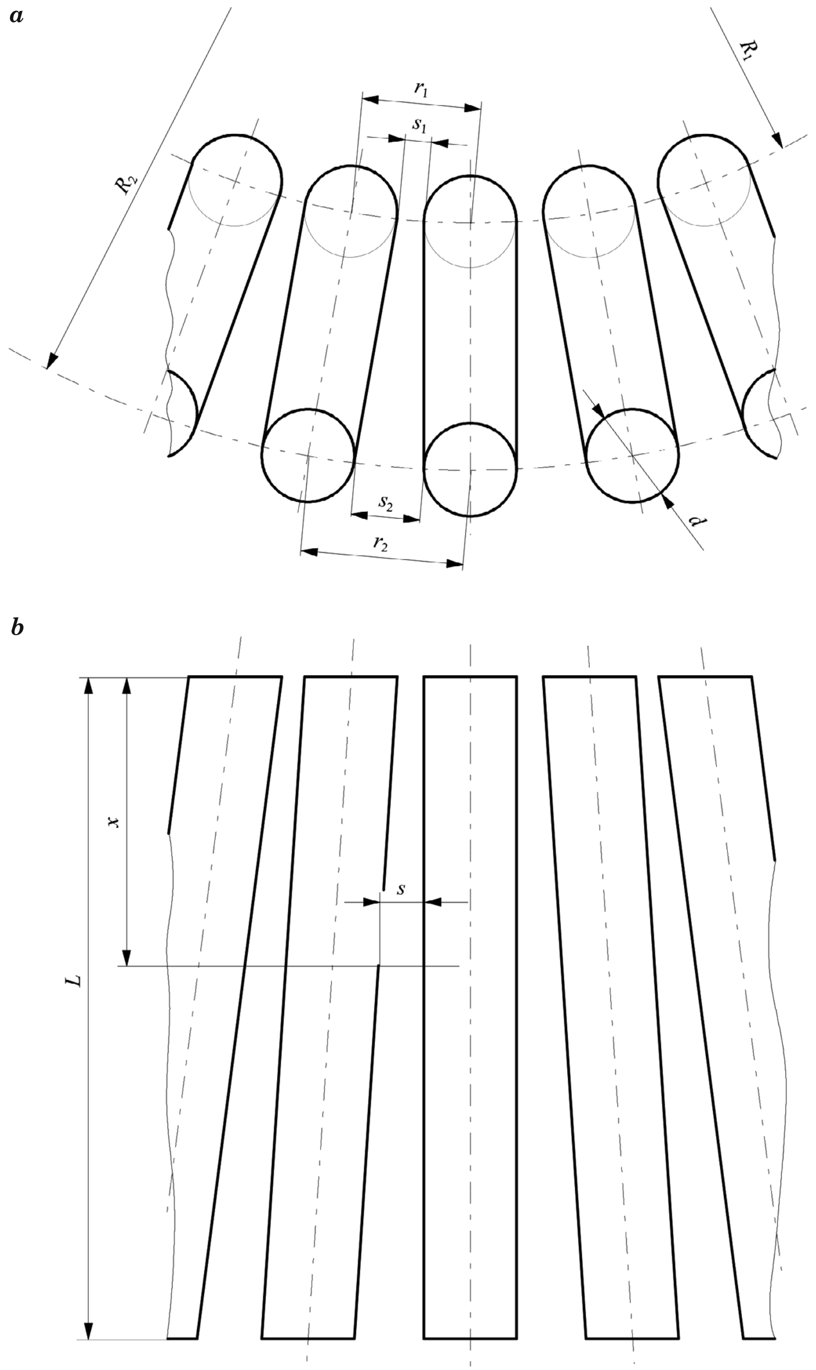

Fig. 2. Arrangement of bars in a conical screen: a – rear view, b – top view

Formulas (1) and (2) are substituted and equation (3) is divided by equation (4) to produce the following dependence:

$$\frac{2 \cdot \pi \cdot R_2}{2 \cdot \pi \cdot R_1} = \frac{n \cdot (s_2 + d)}{n \cdot (s_1 + d)} \tag{5}$$

which can be transformed to:

$$R_2 = R_1 \cdot \frac{s_2 + d}{s_1 + d} \tag{6}$$

The above formula suggests that radius R_2 at which bars are fixed to the ring at the end of the screen is determined by four parameters: radius R_1 at which bars are fixed to the ring at the beginning of the screen, groove width s_1 and s_2 at the beginning and at the end the screen, respectively, and bar diameter d.

Groove width at a given point on the screen is determined by the distance from the beginning of the screen. In line with the similar triangles theorem, the result is:

$$\frac{(s - s_1)}{x} = \frac{(s_2 - s_1)}{L} \tag{7}$$

Formula (7) is transformed, and groove width s is calculated with the use of the below equation:

$$s = \frac{(s_2 - s_1) \cdot x}{L} + s_1 \tag{8}$$

Seeds whose thickness is identical to the calculated groove width should pass through the screen at that point into the corresponding collecting bucket, whereas thicker seeds should be set into motion by the rotating screen and should move along the rotation axis until they reach a groove opening with the corresponding size.

Based on general trigonometric identities, the opening angle γ of bars can be calculated with the use of the below formula:

$$\gamma = \text{arc tg} \frac{s_2 - s_1}{L} \tag{9}$$

The slant height of a truncated cone meets the cone axis at angle β which can be determined from the below trigonometric equation:

$$\sin \beta = \frac{R_2 - R_1}{L} \tag{10}$$

Equations (1) to (4) are substituted into formula (10) to produce:

$$\beta = \text{arc} \sin \frac{n \cdot (s_2 - s_1)}{2 \cdot \pi \cdot L} \tag{11}$$

Geometrical parameters of seeds

The process of designing new devices for seed cleaning and sorting requires knowledge about the physical properties of the separated material (GROCHOWICZ 1994). The relevant data are used select the appropriate screen and the sequence of separation processes to produce material of desired quality (GROCHOWICZ 1994, MAJEWSKA et al. 2000). Information about the physical parameters of seeds is also needed when modeling and designing other processes, including seed production, harvesting, transport, cleaning, sorting, drying, storage and processing (GROCHOWICZ 1994, ÇALIŞIR et al. 2005, ALTUNTAS, DEMIRTOLA 2007, BOAC et al. 2010, KALKAN, KARA 2011).

Seeds of the same crop species and variety can also differ in plumpness. Their parameters are influenced by many factors, in particular soil and climatic conditions, cultivation practices, genetic factors, moisture content and even position on the maternal plant (GEODECKI, GRUNDAS 2003, ÇALIŞIR et al. 2005, ALTUNTAS, DEMIRTOLA 2007, YALÇIN et al. 2007, KALKAN, KARA 2011, GRZESIK et al. 2012, MIRZABE et al. 2012, KIM et al. 2014). The designed device poses an alternative to screen separators with longitudinal openings, therefore, the basic geometrical parameters of the separated seeds, in particular distribution of seed thickness, have to be determined.

Table 1 presents the parameters of seeds of principal crop species with moisture content adequate for storage, without classification into groups based on varieties and cultivation practices (the relevant references are cited under the table). The thickness of small seeds (group I – rapeseed, mustard) ranges from 1.1 to 2.5 mm. The thickness of medium-sized seeds (group II) ranges from 1.2 mm (oats and rye) to 6.1 mm (vetch). In the group of principal cereal species (group IIa), seed thickness varies from 1.2 mm to 4.7 mm. The greatest variation in thickness is observed in the group of large seeds (group III).

Table 1

Range of variation in the geometrical properties of selected seeds

Size fraction	Species	Seed group	Seed dimensions thickness [mm]	width [mm]	length [mm]	References
Small	mustard	I	1.1–2.4	1.1–2.7	1.4–3.0	3, 36
	rapeseed		1.2–2.5	1.6–2.8	1.7–2.8	1, 3, 9, 23
Medium	barley	IIa	1.4–4.7	2.0–5.0	7.0–14.6	4, 14, 15, 21, 23
	oats		1.2–3.6	1.4–4.0	8.0–18.6	4, 15, 23
	rye		1.2–4.4	1.5–4.9	5.0–10.5	10, 22, 27
	triticale		1.7–4.2	1.9–4.3	5.3–10.4	10, 29, 37
	wheat		1.4–3.9	1.6–4.5	4.3–10.2	4, 7, 10, 23, 24, 33
	buckwheat	IIb	2.0–4.2	3.0–5.2	4.4–8.0	4, 6, 16, 35
	rice		1.6–2.5	2.0–3.6	5.3–9.8	19, 23
	sunflower		1.7–6.0	3.5–9.9	7.5–24.3	4, 23, 28
	vetch		2.0–6.1	3.2–6.3	3.2–7.5	4, 12, 35
Large	corn	III	2.6–12.8	4.8–16.4	7.7–20.3	13, 23, 25, 30, 32
	faba bean		3.1–9.9	4.8–12.9	7.1–21.8	2, 31, 34, 35
	lupine		2.9–8.5	3.1–8.5	3.9–13.6	5, 8, 11, 20, 35
	pea		3.5–10.1	3.7–10.2	4.0–10.5	4, 17, 20, 35
	soybean		3.3–8.1	5.0–9.5	5.2–11.2	18, 23, 26

1 – Rawa et al. (1990), 2 – Mieszkalski (1991), 3 – Choszcz, Wierzbicki (1994), 4 – Grochowicz (1994), 5 – Zduńczyk et al. (1996), 6 – Kim et al. (2002), 7 – Mabille, Abecasis (2003), 8 – Mańkowski (2004), 9 – Çalişir et al. (2005), 10 – Hebda, Micek (2005), 11 – Lema et al. (2005), 12 – Taser et al. (2005), 13 – Coşkun et al. (2006), 14 – Rybiński, Szot (2006), 15 – Hebda, Micek (2007), 16 – Kram et al. (2007), 17 – Yalçin et al. (2007), 18 – Cho et al. (2008), 19 – Varnamkhasti et al. (2008), 20 – Rybiński et al. (2009), 21 – Sýkorová et al. (2009), 22 – Zdybel et al. (2009), 23 – Boac et al. (2010), 24 – Kalkan, Kara (2011), 25 – Tarighi et al. (2011), 26 – Xu et al. (2011), 27 – Jouki et al. (2012), 28 – Mirzabe et al. (2012), 29 – Tomporowski (2012), 30 – Babić et al. (2013), 31 – Kara et al. (2013), 32 – Akinyosoye et al. (2014), 33 – Kim et al. (2014), 34 – Sundaram et al. (2014), 35 – Kaliniewicz et al. (2015), 36 – Mieszkalski et al. (2015), 37 – Suleiman et al. (2015).

In corn, this parameter ranges from 2.6 mm to even 12.8 mm. The data presented in Table 1 indicate that the parameters of the evaluated seeds fall into the below range of values:
– seed thickness – 1.1÷12.8 mm,
– seed width – 1.1÷16.4 mm,
– seed length – 1.4÷21.8 mm.

Parameters of a conical bar screen

Groove width in a conical bar screen for cleaning and sorting seeds of three size fractions is presented in Table 2. As previously indicated, groove width at the beginning of the screen should be somewhat smaller than the thickness of the smallest seeds of the principal species, whereas groove width at the end of the screen should be somewhat larger than the thickness of the largest seeds of the principal species. Therefore, groove width for small seeds (group I) should be set at 1 mm at the beginning of the screen and 3 mm at the end of the screen. For the seeds of major cereal species (group IIa), groove width should be set at 1 mm and 5 mm, respectively. The resulting screen can also be used for sorting seeds of small-seeded legumes. Medium-sized seeds should be separated with the use of screens with groove width of 1 mm and 6.5 mm, and large seeds – with the use of screens with groove width of 2.5 mm and 13 mm, respectively. A universal device for sorting seeds from all size fractions should be fitted with a screen with groove width of 1 mm and 13 mm, respectively. Similar conclusions relating to groove width were formulated by KALINIEWICZ (2013b) in a study of a string sieve.

Table 2

Parameters of a conical bar screen

Screen parameter	Seed group						
	I	IIa	I+IIa	IIb	I+II	III	I+II+III
s_1 [mm]	1.0	1.0	1.0	1.5	1.0	2.5	1.0
s_2 [mm]	3.0	5.0	5.0	6.5	6.5	13.0	13.0
L [mm]	534	1067	1067	889	1467	1120	3200
γ [°]	0.215	0.215	0.215	0.322	0.215	0.537	0.215

I – small seeds (mustard, rapeseed),
IIa – principal cereal species (barley, oats, rye, triticale and wheat),
IIb – other medium-sized seeds (buckwheat, rice, sunflower, vetch),
II – medium-sized seeds (IIa + IIb),
III – large seeds (corn, faba bean, lupine, pea, soybean).

For the sorting process to effectively separate seeds into at least 3 size fractions, the seeds of a given species and variety should be sorted along a screen segment of minimum 30 cm. The coefficients of variation in seed dimensions are generally determined in the range of 6% to 20%. For the needs of this study, the coefficient of variation in seed thickness was set at CV = 12%. If groove width at the beginning of the screen is equal to the minimum value of a given dimension of the separated seeds, and the range (i.e. the difference between the maximum and minimum values) corresponds to six values of standard deviation SD in seed thickness, then formula (7) takes the following form:

$$\frac{s_1 + 6 \cdot \mathrm{SD} - s_1}{x} = \frac{s_2 - s_1}{L} \tag{12}$$

The equation can be transformed as follows:

$$L = \frac{x \cdot (s_2 - s_1)}{6 \cdot \mathrm{SD}} \tag{13}$$

Standard deviation of a parameter can be determined from the formula for calculating its coefficient of variation CV. In the analyzed case, the formula takes the following form:

$$\mathrm{CV} = 100 \cdot \frac{\mathrm{SD}}{s_1 + 3 \cdot \mathrm{SD}} \tag{14}$$

The equation can be transformed to produce:

$$\mathrm{SD} = \frac{\mathrm{CV} \cdot \mathrm{s}_1}{100 - 3 \cdot \mathrm{CV}} \tag{15}$$

The resulting dependence is substituted into formula (13) to produce the following equation:

$$L = \frac{x \cdot (s_2 - s_1) \cdot (100 - 3 \cdot \mathrm{CV})}{6 \cdot \mathrm{CV} \cdot \mathrm{s}_1} \tag{16}$$

The experimental values of the analyzed parameters, $x = 300$ mm and CV = 12%, are introduced into the above equation:

$$L = \frac{800}{3} \cdot \frac{s_2 - s_1}{s_1} \tag{17}$$

The length of a conical bar screen, determined with the above formula, is given in Table 2. The universal sorting device should have a bar screen with an estimated length of 3.2 m. However, only a small portion of such a screen (30 cm segment) would be used to sort seeds of a given crop species. For this reason, two variants of the proposed device have been designed: one for sorting small seeds, including seeds of small-seeded legumes and seeds of major cereal species (variant 1 for group I+IIa seeds), and the other for sorting large seeds (variant 2 for group III seeds). Each variant will be equipped with a conical bar screen with an estimated length of 1.1 m. Variant 1 will be used to separate seeds of buckwheat, rice and small-seeded varieties of sunflower and vetch, whereas variant 2 will be used to separate seeds of large-seeded varieties of the above species. The opening angle of screen bars will be $\gamma = 0.215^o$ in variant 1 and $\gamma = 0{,}537^o$ in variant 2.

According to GROCHOWICZ (1994), the diameter of rotating cylindrical screens and industrial cylindrical graders ranges from 400 mm to 800 mm. Therefore, the radius at which bars are fixed to the clamp ring at the beginning of the screen should be minimum 200 mm, and the radius at which bars are fixed at the end of the screen should not exceed 400 mm. In a given screen variant, the number of grooves is determined by the diameter of screen bars. Based on formulas (3) and (4), the number of grooves should meet the following condition:

$$\frac{2 \cdot \pi \cdot R_1}{s_1 + d} \leq n \leq \frac{2 \cdot \pi \cdot R_2}{s_2 + d} \tag{18}$$

The limiting values of radii at which bars are fixed to clamp rings are substituted into the above formula to produce:

$$\frac{1256.6}{s_1 + d} \leq n \leq \frac{2513.5}{s_2 + d} \tag{19}$$

The left side of the equation representing $n_{\min}$ is rounded up to the nearest integer, and the right side representing $n_{\max}$ is rounded down to the nearest integer. Bars with a diameter of 5 mm to 10 mm will be used to produce a rigid structure, minimize screen weight and produce screens with the highest number of grooves. The parameters of both variants are presented in Table 3. The screen for sorting small seeds and seeds of principal cereal species (variant 1) can be made of bars whose diameters cover the entire range of proposed values. The number of grooves may range from 115 (bar diameter d = 10 mm) to even 251 (bar diameter d = 5 mm), depending on bar diameter. The base angle of a conical bar screen decreases with an increase in bar diameter from around 3.8° to around 8.4° in variant 1.

The diameter of bars in a conical screen designed for large seeds is more limited and should not exceed 8.12 mm. A screen comprising bars with a diameter of 8.12 mm will have 119 grooves. When bars with a diameter of 9–10 mm are used, the screen will have 101 to 114 grooves and an estimated base angle of 8.8–10°.

Table 3

Parameters of two variants of the proposed conical bar screen

Variant	Parameter	Bar diameter d [mm]					
		5	6	7	8	9	10
V-1 (s_1 = 1 mm, s_2 = 5 mm, L = 1.1 m)	n_{min} [–]	210	180	157	140	126	115
	n_{max} [–]	251	228	209	193	179	167
	R_2/R_1 [–]	1.67	1.57	1.50	1.44	1.40	1.36
	β_{min} [°]	6.981	5.980	5.213	4.647	4.182	3.816
	β_{max} [°]	8.353	7.583	6.947	6.413	5.946	5.546
V-2 (s_1 = 2.5 mm, s_2 =13 mm, L = 1.1 m)	n_{min} [–]	–	–	–	–	110	101
	n_{max} [–]	–	–	–	–	114	109
	R_2/R_1 [–]	–	–	–	–	1.91	1.84
	β_{min} [°]	–	–	–	–	9.620	8.826
	β_{max} [°]	–	–	–	–	9.973	9.532

Conclusions

The proposed variants of a conical bar separator pose an alternative to a conventional separator with a set of screens with longitudinal openings. The first variant has been designed for separating buckwheat seeds, rapeseeds and seeds of principal cereal species, whereas the second variant can be used to separate large seeds. The width of screen grooves changes continuously along the screen and corresponds to the size of the separated seeds. Seeds of a given species and variety could be separated by adjusting the position of collecting buckets under the screen. Screens for separating seeds of major agricultural crops should have an estimated length of 1.1 mm, and groove width at the beginning and end of the screen should equal 1 mm and 5 mm, respectively, in variant 1, and 2.5 mm and 13 mm, respectively, in variant 2. Bar diameter can range from 5 mm to 10 mm in variant 1, and from 8.12 mm to 10 mm in variant 2.

References

AKINYOSOYE S.T., ADETUMBI J.A., AMUSA O.D., OLOWOLAFE M.O., OLASOJI J.O. 2014. *Effect of seed size on in vitro seed germination, seedling growth, embryogenic callus induction and plantlet regeneration from embryo of maize (Zea mays L.) seed*. Nigerian Journal of Genetics, 28: 1–7. http://dx.doi.org/10.1016/j.nigjg.2015.06.001.

ALTUNTAS E., DEMIRTOLA H. 2007. *Effect of moisture content on physical properties of some grain legume seeds*. New Zealand Journal of Crop and Horticultural Science, 35(4): 423–433. http://dx.doi.org/10.1080/01140670709510210.

BABIĆ L.J., RADOJÇIN M., PAVKOV I., BABIĆ M., TURAN J., ZORANOVIĆ M., STANIŞIĆ S. 2013. *Physical properties and compression loading behaviour of corn seed*. International Agrophysics, 27: 119–126. http://dx.doi.org/10.2478/v10247-012-0076-9.

BOAC J.M., CASADA M.E., MAGHIRANG R.G., HARNER III J.P. 2010. *Material and interaction properties of selected grains and oilseeds for modeling discrete particles*. Transaction of ASABE, 53(4): 1201–1216. http://dx.doi.org/10.13031/2013.32577.

ÇALIŞIR S., MARAKOĞLU T., ÖĞÜT H., ÖZTÜRK Ö. 2005. *Physical properties of rapeseed (Brassica napus oleifera L.)*. Journal of Food Engineering, 69: 61–66. http://dx.doi.org/10.1016/j.jfoodeng.2004.07.010.

CHO G.T., LEE J., MOON J.K., YOON M.S., BAEK H.J., KANG J.H., KIM T.S., PAEK N.CH. 2008. *Genetic diversity and population structure of Korean soybean landrace [Glycine max (L.) Merr.]*. Journal of Crop Science and Biotechnology, 11(2): 83–90. http://dx.doi.org/10.3390/ijms17030370.

CHOSZCZ D., WIERZBICKI K. 1994. *A study the separation of field bedstraw (Galium aparine) seeds from rape and mustard seeds with the use of their geometrical and aerodynamic properties*. Acta Acad. Agricult. Tech. Olst. Aedif. Mech., 25: 61–69 (article in Polish with an abstract in English).

COŞKUN M.B., YALÇIN Í., ÖZARSLAN C. 2006. *Physical properties of sweet corn seed (Zea mays saccharata Sturt.)*. Journal of Food Engineering, 74: 523–528. http://dx.doi.org/10.1016/j.jfoodeng.2005.03.039.

GEODECKI M., GRUNDAS S. 2003. *Characterization of geometrical features of single winter and spring wheat kernels*. Acta Agrophysica, 2(3): 531–538 (article in Polish with an abstract in English).

GROCHOWICZ J. 1994. *Maszyny do czyszczenia i sortowania*. Wydawnictwo Akademii Rolniczej, Lublin.

GRZESIK M., JANAS R., GÓRNIK K., ROMANOWSKA-DUDA Z. 2012. *Biological and physical methods of seed production and processing*. Journal of Research and Applications in Agricultural Engineering, 57(3): 147–152 (article in Polish with an abstract in English).

HEBDA T., MICEK P. 2005. *Dependences between geometrical features of cereal grain*. Inżynieria Rolnicza, 6: 233–241 (article in Polish with an abstract in English).

HEBDA T., MICEK P. 2007. *Geometric features of grain for selected corn varieties*. Inżynieria Rolnicza, 5(93): 187–193 (article in Polish with an abstract in English).

JADWISIEŃCZAK B., JADWISIEŃCZAK K., KALINIEWICZ Z., PAWŁOWSKI K. 2016. *Przesiewacz szczelinowy*. Patent application No. P.418250 of 8.08.2016.

JOUKI M., EMAM-DJOMEH Z., KHAZAEI N. 2012. *Physical properties of whole rye seed (secale cereal)*. International Journal of Food Engineering, 8(4): article 7. http://dx.doi.org/10.1515/1556-3758.2054.

KALINIEWICZ Z. 2013a. *A theoretical analysis of cereal seed screening in a string sieve*. Technical Sciences, 16(3): 234–247.

KALINIEWICZ Z. 2013b. *String sieve: design concept and parameters*. Technical Sciences, 16(2): 119–129.

KALINIEWICZ Z. 2015. *Sito strunowe*. Patent No. 218968, patent application of 24.10.2011, published in the WUP of 27.02.2015.

KALINIEWICZ Z., DOMAŃSKI J. 2013. *A movable string sieve – analysis of seed screening*. Technical Sciences, 16(4): 253–264.

KALINIEWICZ Z., MARKOWSKI P., ANDERS A., JADWISIEŃCZAK K. 2015. *Frictional properties of selected seeds*. Technical Sciences, 18(2): 85–101.

KALKAN F., KARA M. 2011. *Handling, frictional and technological properties of wheat as affected by moisture content and cultivar*. Powder Technology, 213: 116–122. http://dx.doi.org/10.1016/j.powtec.2011.07.015.

KARA M., SAYINCI B., ELKOCA E., ÖZTÜRK I., ÖZMEN T.B. 2013. *Seed size and shape analysis of registered common bean (Phaseolus vulgaris L.) cultivars in Turkey using digital photography*. Tarym Bilimleri Dergisi – Journal of Agricultural Sciences, 19: 219–234.

KIM Y.B., KIM S.L., LEE K.CH., CHANG K.J., KIM N.S., SHIN Y.B., PARK CH.H. 2002. *Interspecific hybridization between Korean buckwheat landraces (Fagopyrum esculentum Moench) and self-fertilizing buckwheat species (F. homotropicum Ohnishi)*. Fagopyrum, 19: 37–42.

KIM K.H., SHIN S.H., PARK S., PARK J.C., KANG C.S., PARK C.S. 2014. *Relationship between pre-harvest sprouting and functional markers associated with grain weight, TaSUS2-2B, TaGW2-6A, and TaCWI-A1, in Korean wheat cultivars*. SABRO Journal of Breeding and Genetics, 46(2): 319–328.

KRAM B.B., WOLIŃSKI J., WOLIŃSKA A. 2007. *Comparative studies on geometric traits of nutlets with and without seed cover in Red corolla buckwheat*. Acta Agrophysica, 9(3): 657–664 (article in Polish with an abstract in English).

LEMA M., SANTALLA M., RODIÑO A.P., DE RON A.M. 2005. *Field performance of natural narrow-leafed lupin from the northwestern Spain*. Euphytica, 144: 341–351. http://dx.doi.org/10.1007/s10681-005-8187-z.

MABILLE F., ABECASSIS J. 2003. *Parametric modelling of wheat grain morphology: a new perspective*. Journal of Cereal Science, 37: 43–53. http://dx.doi.org/10.1006/jcrs.2002.0474.

MAJEWSKA K., GUDACZEWSKI W., FORNAL Ł. 2000. *Size of wheat grains and rheological properties of dough*. Inżynieria Rolnicza, 5(16): 153–162 (article in Polish with an abstract in English).

MAŃKOWSKI S. 2004. *Metoda rozdrabniania nasion łubinu i wydzielania cząstek okrywy nasiennej*. Doctoral dissertation, Faculty of Technical Sciences, UWM in Olsztyn.

MIESZKALSKI L. 1991. *Influence of moisture on the geometrical features of faba bean seeds and also variation of these features with given variety*. Acta Acad. Agricult. Tech. Olst. Aedif. Mech., 22: 43–55 (article in Polish with an abstract in English).

MIESZKALSKI L., ŻUK Z., SZCZYGLAK P. 2015. *Mathematical modeling of the shape of the seed of white mustard (Sinapis alba L.)*. Postępy Techniki Przetwórstwa Spożywczego, 1: 62–66 (article in Polish with an abstract in English).

MIRZABE A.H., KHAZAEI J., CHEGINI G.R. 2012. *Physical properties and modeling for sunflower seeds*. Agricultural Engineering International: The CIGR e-journal, 14(3): 190–202.

RAWA T., WIERZBICKI K., PIETKIEWICZ T. 1990. *Potential effectiveness of rape seeds cleaning according to geometrical characteristics*. Acta Acad. Agricult. Tech. Olst. Aedif. Mech., 20: 117–129 (article in Polish with an abstract in English).

RYBIŃSKI W., SZOT B. 2006. *Estimation of genetic variability of yielding traits and physical properties of seeds of spring barley (Hordeum vulgare L.) mutants*. International Agrophysics, 20(3): 219–227.

RYBIŃSKI W., SZOT B., RUSINEK R., BOCIANOWSKI J. 2009. *Estimation of geometric and mechanical properties of seeds of Polish cultivars and lines representing selected species of pulse crops*. International Agrophysics, 23: 257–267.

SULEIMAN R., XIE K., ROSENTRATER K. 2015. *Physical and thermal properties of chia, kañiwa, triticale and farro as a function of moisture content*. Agricultural and Biosystems Engineering Conference Proceedings and Presentations, Paper Number: 152189412. doi: 10.13031/aim.20152189412.

SUNDARAM P.K., SINGH A.K., KUMAR S. 2014. *Studies on some engineering properties of faba bean seeds*. Journal of AgriSearch, 1(1): 4–8.

SYKOROVÁ A., ŞÁRKA E., BUBNÍK Z., SCHEJBAL M., DOSTÁLEK P. 2009. *Size distribution of barley kernels*. Czech Journal of Food Science, 27: 249-258.

TARIGHI J., MAHMOUDI A., ALAVI N. 2011. *Some mechanical and physical properties of corn seed (Var. DCC 370)*. African Journal of Agricultural Research, 6(16): 3691–3699. doi: 10.5897/AJAR10.521.

TASER O.F., ALTUNTAS T., OZGOZ E. 2005. *Physical properties of Hungarian and common vetch seeds*. Journal of Applied Sciences, 5(2): 323–326. http://dx.doi.org/10.3923/jas.2005.323.326.

TOMPOROWSKI A. 2012. *Filling model for the working multi-disc biomass grain grinding unit*. The Archive of Mechanical Engineering, LIX(2): 2155–174. http://dx.doi.org/10.2478/v10180-012-0008-z.

VARNAMKHASTI M.G., MOBLI H., JARAFI A., KEYHANI A.R., SOLTANABADI M.H., RAFIEE S., KHEIRALIPOUR K. 2008. *Some physical properties of rough rice (Oryza sativa L.) grain*. Journal of Cereal Science, 47: 496–501. http://dx.doi.org/10.1016/j.jcs.2007.05.014.

XU Y., LI H.N., LI G.J., WANG X., CHENG L.G., ZHANG Y.M. 2011. *Mapping quantitative trait loci for seed size traits in soybean (Glycine max L. Merr.)*. Theoretical and Applied Genetics, 122(3): 581–594. http://dx.doi.org/10.1007/s00122-010-1471-x.

YALÇIN Y., ÖZARSLAN C., AKBAŞ T. 2007. *Physical properties of pea (Pisum sativum) seed*. Journal of Food Engineering, 79: 731–735. http://dx.doi.org/10.1016/j.jfoodeng.2006.02.039.

ZDUŃCZYK Z., JUŚKIEWICZ J., FLIS M., AMAROWICZ R., KREFFT B. 1996. *The chemical composition and nutritive value of low-alkaloid varieties of white lupin. 1. Seed, cotyledon and seed coat characteristics*. Journal of Animal and Feed Sciences, 5: 63–72.

ZDYBEL A., GAWŁOWSKI S., LASKOWSKI J. 2009. *Influence of moisture content on some physical properties of rye grains*. Acta Agrophysica, 14(1): 243–255 (article in Polish with an abstract in English).