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VARIABILITY AND CORRELATION OF THE SELECTED PHYSICAL PROPERTIES OF PUMPKIN SEED (*CUCURBITA PEPO L.*)

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ABSTRACT

Basic dimensions (length, width and thickness), critical velocity of transporting seeds, sliding friction angle and the mass of pumpkin seeds, obtained from four fruit of various mass were determined. Based on the measurements, volume and thickness of each seed and its spherical index were calculated. Interdependence between the tested properties and indexes was evaluated based on the test for independent samples, analyses of variance, correlation and regression. It was found that the seeds mass is the most variable property and their length is the least variable. Empty and full pumpkin seeds should be separated with a pneumatic separator, where a vertical air stream of velocity approx. 5 $m \cdot s^{-1}$ is a separating element. Length and mass of seeds may be used at separation of seed material into quality fractions. As a result of separating the smallest seed fraction, a seed material may be obtained in which after the process of removing the fruit-seed coat, 95% of ripe seeds will be available.

The list of symbols:

k	– seeds volume index,
K_m, K_w	– spherical indexes of a seed,
m_n, m_p	– seed mass without fruit-seed coat and seed mass (g),
S	– standard deviation of a property,
T, W, L	– thickness, width and length of a seed (mm),
v	– critical velocity of transporting seeds ($m \cdot s^{-1}$),
V	– volume of a seed (cm^3),
V_p	– total volume of seeds in a sample (cm^3),
V_s	– coefficient of the feature variability (%),
x, x_{max}, x_{min}	– average, maximum and minimum value of the feature,
γ	– sliding friction angle of a seed on steel (°),
ρ	– density of a seed ($g \cdot cm^{-3}$).

Introduction and the objective of the paper

Cucurbita pepo is an annual plant, which belongs to the cucurbitales family. It was brought to Europe in the 16th century by Spanish along with the conquest of the Middle America. On account of the dimensions it achieves and edible pulp and seeds, is has been cultivated for many years as a vegetable and a fodder plant. A pumpkin is a stenthermal plant, which needs big amount of water during the entire vegetation period. Fertile soils, which are heated is a short time, with a neutral reaction, permeable to air with a limited tendency for fast crusting are the most recommended for cultivation (*Polowa*... 2000; *Rośliny*... 2010).

The pumpkin fruit is a big, round, pear-shaped, cylindrical or disc-shaped berry, hard outside, filled with a pulp, with seeds inside. A fruit may also be a decoration after hollowing out and is frequently used for Halloween. The pulp of pumpkin is a dietary product, which is the most frequently used as an addition to salads or meat and sometimes processed into jam. Pumpkin flowers are used for preparing tasty salads (Dedilo, 1992; Sojak, 1999; Sacilik, 2007; Balkaya et al., 2010; *Rośliny*... 2010; Jacobo-Valenzuela et al., 2011; Nawirska-Olszańska, 2011).

Pumpkin fruit grown for seeds have to reach full maturity, which is necessary for seeds to have appropriate aroma and taste (*Rośliny*... 2010; Sosińska and Panasiewicz, 2012).

Currently, seeds for industrial scale are obtained with specialist combine harvesters, equipped with a characteristic pick-up assembly with studs. Seeds taken out of fruit after harvesting must be dried out (Can, 2007; Sacilik, 2007).

During the processes of obtaining seeds, their cleaning, sorting, transport, processing and sowing, knowledge on the the scope of variability of physical properties of the processed seed material and interdependencies occurring between those properties is necessary. It allows planning and controlling the above processes and gives a possibility of selecting parameters to functioning of devices and machines.

The objective of the paper is determination of the scope of variability of the selected physical properties of seeds of cucurbita pepo and interdependencies occurring between them on account of using those data during division of the material into quality classes.

Material and methods

Seeds of cucurbita pepo of Danka Polka cultivar constituted a research material. Seeds were obtained manually from 4 randomly selected ripe pumpkin seeds, which come from crops of 2011 from a plantation located in Bystrzyce (lubelski province) – 51.31°N and 22.70ºE. Mass of pumpkin fruit was: 4.0; 4.3; 6.3 and 7.6 kg. All seeds were taken out of fruit and then placed in a dry, air permissible place on paper towels in a manner which did not allow their touching each other. After 7 days of drying, 300 seeds were selected from each sample, basing on an alternative method (Greń, 1984).

Critical velocity of transporting seeds was determined with the use of a pneumatic classifier of Petkus company type K-293 with precision to 0.11 $m \cdot s^{-1}$. Measurements were taken according to the method described in the paper written by Kaliniewicz and Trojanowski (2011).

Measurements of 3 basic dimensions of seeds with the use of electronic calliper with precision to 0.01 mm were carried out. Sliding friction angle was determined on the inclined plane of a regulated inclination angle with a friction plane made of steel sheet (GPS – *Ra*=0.46 μm). Each seed was placed along a longitudinal axis in parallel to the inclination of a plane, and the value of sliding friction angle was read out from a protractor with precision up to 1°.

Mass of pumpkin seeds and seeds following a manual removal of a fruit-seed coat was read out from the laboratory scale WAA 100/C/2 with precision up to 0.1 mg.

At determination of the shape of seeds, spherical indexes were calculated from patterns (Grochowicz, 1994):

$$K_m = \frac{W}{L} \tag{1}$$

$$K_w = \frac{T}{L} \tag{2}$$

Volume V of each seed was determined according to the following relation:

$$V = k \cdot T \cdot W \cdot L \tag{3}$$

where coefficient of the seeds volume k was determined by means of experiment based on the measurement of length, width and thickness of 100 randomly selected seeds from material, which remained after preparing research samples. Seeds were located in a graduated cylinder of 250 cm^3 volume (half-filled with water) and they were immersed with a piece of a sieve mounted on the rod. Based on the determined volume and dimensions an average value of the volumetric coefficient was calculated from the formula:

$$k = \frac{V_p}{\sum T \cdot W \cdot L} \tag{4}$$

Finally, volume of each pumpkin seed was calculated from the relation:

$$V = 0.539 \cdot T \cdot W \cdot L \tag{5}$$

Density ρ of seeds was determined from the pattern:

$$\rho = \frac{m}{V} \tag{6}$$

Results of measurements and calculations were prepared statistically with the use of Statistica programme (version 10) using generally known statistical procedures, such as test t for independent samples, analysis of one-factor variance, correlation analysis and analysis of linear regression (Rabiej, 2012). Calculations were carried out at the level of significance of 0.05.

Separation indexes of mixture of empty and full pumpkin seeds were determined from the formula (Rawa and Semczyszyn, 1988):

$$\delta = \left| \frac{x_1 - x_2}{3(S_1 + S_2)} \right| \tag{7}$$

where indexes 1 and 2 at symbols mean average value and standard deviation of a given physical property respectively of full an empty seeds.

Results and Discussion

Characteristic of physical properties of pumpkin seeds from particular batches was presented in Table 1. The highest values of coefficient of variability were reported for the mass of seeds and the lowest for their length. Generally, one may state that the analysed physical properties of seeds change in the following scopes:

- critical velocity of distribution – from 3.03 to 7.98 m·s^{-1},
- thickness – from 1.83 to 5.04 mm,
- width – from 9.57 to 16.98 mm,
- length – from 16.06 to 27.10 mm,
- sliding friction angle – from 14 to 42°,
- mass – from 0.0350 to 0.5254 g.

Table 1

Statistical parameters of distribution of physical properties of pumpkin seeds

Seeds batch	Physical property	x_{min}	x_{max}	x	S	V_s
D-4.0	v	3.03	7.98	6.96^a	0.795	11.42
	T	2.30	4.62	3.33^b	0.307	9.21
	W	9.57	14.35	12.25^d	0.798	6.51
	L	16.06	23.64	18.75^d	1.065	5.68
	γ	16	32	21.6^c	2.769	12.80
	m_p	0.0444	0.3680	0.236^d	0.041	17.51
D-4.3	v	3.03	7.98	6.71^b	0.908	13.52
	T	1.83	3.72	2.76^d	0.302	10.93
	W	10.14	14.07	12.63^c	0.656	5.20
	L	17.77	24.26	21.43^c	1.109	5.17
	γ	18	42	23.0^b	3.740	16.26
	m_p	0.0351	0.3803	0.269^c	0.049	18.13
D-6.3	v	3.03	7.43	6.12^c	1.380	22.54
	T	1.85	4.45	3.11^c	0.372	11.96
	W	10.90	15.89	13.50^b	0.775	5.74
	L	20.61	27.10	23.66^b	0.940	3.97
	γ	19	40	26.5^a	3.656	13.81
	m_p	0.0350	0.4115	0.297^b	0.091	30.68
D-7.6	v	3.03	7.43	6.61^b	0.892	13.50
	T	2.20	5.04	3.53^a	0.361	10.23
	W	11.01	16.98	14.83^a	0.820	5.53
	L	20.92	26.33	24.09^a	0.912	3.78
	γ	14	32	21.2^c	3.108	14.65
	m_p	0.0963	0.5254	0.368^a	0.066	17.89

a, b, c – different letters refer to statistically significant differences between seeds batches

Analysed seeds on account of dimensions and mass are higher than the ones investigated by Joshi et al. (1993).

Spread of the investigated physical properties of pumpkin seeds is slightly higher than the data presented by Ebrahimzadeh et al. (2013), and lower than the results of Milani et al. (2007). The investigated seeds are bigger than the dimensions and mass of seeds of *cucurbita moschata* (Balkaya et al., 2010; Jocobo-Valenzuela, 2011), *Citrullus colocynthis* (Abu Shieshaa et al., 2007; Bande et al., 2012) and calabash (Pradhan et al., 2013) and comparable with mixtures of *cucurbita moschata* and *cucurbita maxima* (Karaağaç and Balkaya, 2013). Moreover, their size on account of thickness is comparable with watermelon seeds (Seyed et al., 2006; Koocheki et al., 2007) and seeds of the selected grains cultivars (Hebda and Micek, 2005; 2007).

Average values of a given property for particular batches of seeds in majority of cases differ from each other. It was reported that along with the increase of the mass of pumpkin fruit, also average width, length and mass of seeds increases.

Statistical parameters of volume, density and spherical indexes of seeds were presented in Table 2. The lowest value of the coefficient of variability was reported for coefficient K_m. It is within 4.68 to 5.86%. The highest value of the coefficient of variability was reported for the density of seeds from batch D-6.3 (30.56%). When generalizing, one may notice that the analysed indexes of pumpkin seeds are within the following ranges:

– spherical coefficient K_m – 0.440÷0.790,
– spherical coefficient K_w – 0.087÷0.256,
– volume – 0.209÷1.051 cm^3,
– density – 0.120÷1.052 $g \cdot cm^{-3}$.

Table 2
Statistical parameters of distributions of calculated indexes of pumpkin seeds

Seeds batch	Index	x_{min}	x_{max}	x	S	V_s
D-4.0	K_m	0.534	0.790	0.654^a	0.037	5.60
	K_w	0.127	0.256	0.178^a	0.017	9.31
	V	0.224	0.638	0.415^c	0.066	15.97
	ρ	0.124	0.816	0.572^b	0.085	14.78
D-4.3	K_m	0.440	0.686	0.590^c	0.033	5.60
	K_w	0.087	0.184	0.129^d	0.014	11.15
	V	0.209	0.618	0.404^c	0.063	15.61
	ρ	0.150	1.052	0.671^a	0.116	17.34
D-6.3	K_m	0.497	0.647	0.570^d	0.027	4.68
	K_w	0.087	0.186	0.132^c	0.015	11.53
	V	0.248	0.836	0.539^b	0.093	17.31
	ρ	0.141	1.011	0.553^{bc}	0.169	30.56
D-7.6	K_m	0.490	0.778	0.616^b	0.036	5.86
	K_w	0.089	0.220	0.147^b	0.016	10.57
	V	0.341	1.051	0.682^a	0.094	13.73
	ρ	0.120	0.968	0.549^c	0.120	21.92

a, b, c – different letters refer to statistically significant differences between seeds batches

Spread of the value of shape indexes is in accordance with data obtained by Joshi et al. (1993). It also corresponds to the range of changes of the above indexes for seeds of *cucurbita moschata* (Balkaya et al., 2010), *citrullus colocynthis* (Abu Shieshaa et al., 2007) and calabash (Pradhan et al., 2013).

Based on the t test for independent tests (Table 1) it was found that empty and full seeds of cucurbita pepo differ statistically significantly on account of the critical velocity of transportation, thickness, length, sliding friction angle, mass, spherical and density indexes. Statistically significant differences between empty and full seeds were not reported only for their width and volume. On account of proportionally big disproportion of average values of critical velocity of transportation and density of full and empty seeds, the above properties should be treated as possible separative features.

Results of calculations of the separation index of the mixture of full and empty seeds confirms the above (table 3). As it shows, the analysed index assumes very high values for the critical velocity of transportation and density of seeds. Sorting data on account of critical velocity of transportation of seeds proved that at the use of a division border at the level of 5 $m \cdot s^{-1}$ full and empty seeds may be divided almost in 100%. On account of the simplicity of performance of the above separation process for separation of empty seeds from the seed material, it is recommended to use a pneumatic sorter.

Table 3

Average value and standard deviation of physical properties and the separation index δ of empty and full pumpkin seeds

Physical property/index	Empty seeds		Full seeds		δ
	x	S	x	S	
v	3.27^{b}	0.476	6.84^{a}	0.577	1.132
T	2.78^{b}	0.558	3.21^{a}	0.418	0.147
W	13.55^{a}	1.056	13.28^{a}	1.263	0.038
L	23.38^{a}	2.199	21.88^{b}	2.330	0.111
γ	28.5^{a}	4.794	22.7^{b}	3.550	0.233
m_p	0.1000^{b}	0.038	0.3065^{a}	0.064	0.677
K_m	0.580^{b}	0.038	0.610^{a}	0.046	0.118
K_w	0.119^{b}	0.026	0.148^{a}	0.024	0.197
V	0.483^{a}	0.141	0.512^{a}	0.138	0.034
ρ	0.206^{b}	0.047	0.614^{a}	0.091	0.988

Results of linear correlation analysis corresponding to physical properties of full pumpkin seeds, were presented in Table 4. Critical value of the coefficient of correlation is exceeded at comparing it with a decisive majority of properties. Statistically significant correlation was not reported only for critical velocity of transporting seeds and their thickness, spherical index K_m and mass of seeds with a removed fruit-seeds cover and moreover for the mass of seeds and their sliding friction angle as well as density and for the volume of seeds and their spherical index. The mass of seeds and their length is the most correlated with the mass of seeds without the cover. Coefficient of linear correlation for those couples of properties is respectively 0.757 and 0.735. Joshi et al. reported a very similar value of correlation coefficient between the length of seeds and the mass of seeds with removed fruit-seeds cover (1993). With reference to the mass of seeds and the mass of seeds without a cover, they obtained decisively higher value of the coefficient of correlation, which was 0.96.

Table 4
Pearson's coefficients of correlation between properties and calculated indexes of seeds and seeds without fruit-seed coat

Physical property/index	T	W	L	γ	m_p	K_m	K_w	V	ρ	m_n
v	0.049	-0.230	-0.228	-0.131	-0.064	0.057	0.212	-0.156	0.141	-0.047
T	1	0.452	0.210	-0.197	0.376	0.279	0.686	0.738	-0.776	0.091
W		1	0.745	-0.061	0.799	0.170	-0.174	0.885	-0.427	0.578
L			1	0.143	0.839	-0.528	-0.562	0.769	-0.163	0.735
γ				1	0.041	-0.276	-0.264	-0.078	0.159	0.128
m_p					1	-0.218	-0.302	0.802	-0.049	0.757
K_m						1	0.623	-0.006	-0.311	-0.347
K_w							1	0.047	-0.535	-0.468
V								1	-0.605	0.538
ρ									1	0.114

Critical value of correlation coefficient 0.059

Equations of one variable describing physical properties of seeds and mass of seeds with a removed fruit-seeds coat, for which coefficient of determination is higher than 0.3 were presented in Table 5. As it shows, significant relations occur between such properties as: thickness of seeds, their width and mass as well as mass of seeds without a coat. On account of high value of the coefficient of determination all provided equations may be used at converting some properties into another. Such situation may take place at planning e.g. the processes of cleaning and sorting seeds, where the knowledge of a given property is necessary and on account of the lack of test equipment, a measurement of a completely different property which is properly correlated therewith, is possible. Among the presented equations the highest coefficient of determination (0.704) was obtained for relation of length and the mass of seeds. It corresponds to the results obtained with the use of the analysis of correlation.

Later, it was decided to check whether seeds can be divided according to a specific physical property and whether a levelling of the mass of seeds without a coat can be obtained, as a result of which the seed material will be divided into quality classes of a different market value (e.g. for ripe seeds following removal of fruit-seeds coat – a higher price). It was decided to represent (fig. 1) distribution of the mass of seeds without the coat from 3 fractions of seeds (of almost the same quantity share) for physical properties which are the most correlated with it: the mass of seeds, their length and width. As one can see, any considered physical property of seeds does not guarantee proper division of the seed material into quality classes. Some levelling of this material may be obtained at the use of length of seeds or their mass as a separating property (their distributions are very similar). Separation of the smallest fraction of seeds on account of their length or mass causes that following the removal of the fruit-seed coat from the group of ripe seeds (m_n>0.19 g) approx. 12-13% of material will be reduced and simultaneously 3-4% of seeds, which are not ripe enough, will be there. In the highest class sowing material separated this way only approx. 5% of weakly ripen seeds will occur, which will constitute as much as 60% of seeds in an average class.

Table 5
Equations of one variable describing physical properties of seeds and seeds without fruit-seed coat

Equation	Coefficient of determination R^2	Standard error of estimation
$W = 0.403\,L + 4.454$	0.554	0.843
$W = 15.846\,m_p + 8.421$	0.638	0.760
$W = 20.646\,m_n + 8.792$	0.334	1.030
$L = 1.374\,W + 3.630$	0.554	1.556
$L = 30.709\,m_p + 12.458$	0.704	1.268
$L = 48.427\,m_n + 11.349$	0.540	1.580
$m_p = 0.040\,W - 0.228$	0.638	0.038
$m_p = 0.023\,L - 0.195$	0.704	0.035
$m_p = 1.362\,m_n - 0.011$	0.573	0.042
$m_n = 0.016\,W + 0.002$	0.334	0.029
$m_n = 0.011\,L - 0.027$	0.540	0.024
$m_n = 0.421\,m_p + 0.088$	0.573	0.023

Conclusions

1. The scope of variability of physical properties of pumpkin seeds was within:critical velocity of transportation – 3.03-7.98 $m \cdot s^{-1}$, thickness – 1.83-5.04 mm, width – 9.57-16.98 mm, length – 16.06-27.10 mm, sliding friction angle – 14-42° and mass – 0.0350-0.5254 g.
2. Physical properties, which are the most correlated with each other, are as follows: width, length and the mass of seeds and the mass of seeds without the fruit-seed coat. The introduced equations are characterized with a relatively high coefficient of determination, thus it may be successfully used at converting some properties into another.
3. Empty and full pumpkin seeds differ statistically significantly on account of the critical velocity of transportation, thickness, sliding friction angle, mass, coefficient of shape and density. On account of the simplicity of the execution of the process, the use of pneumatic separator for their separation is suggested. Setting the air stream velocity at the level of 5 $m \cdot s^{-1}$ guarantees almost 100% efficiency of separating empty seeds from sowing material.
4. Length and mass of seeds may be used at separation of seed material into quality classes. Separation of the smallest fraction of seeds allows obtaining more levelled material, where in the highest quality class after the process of removal of the fruit-seed coat, there will be as much as 95% of ripe seeds.

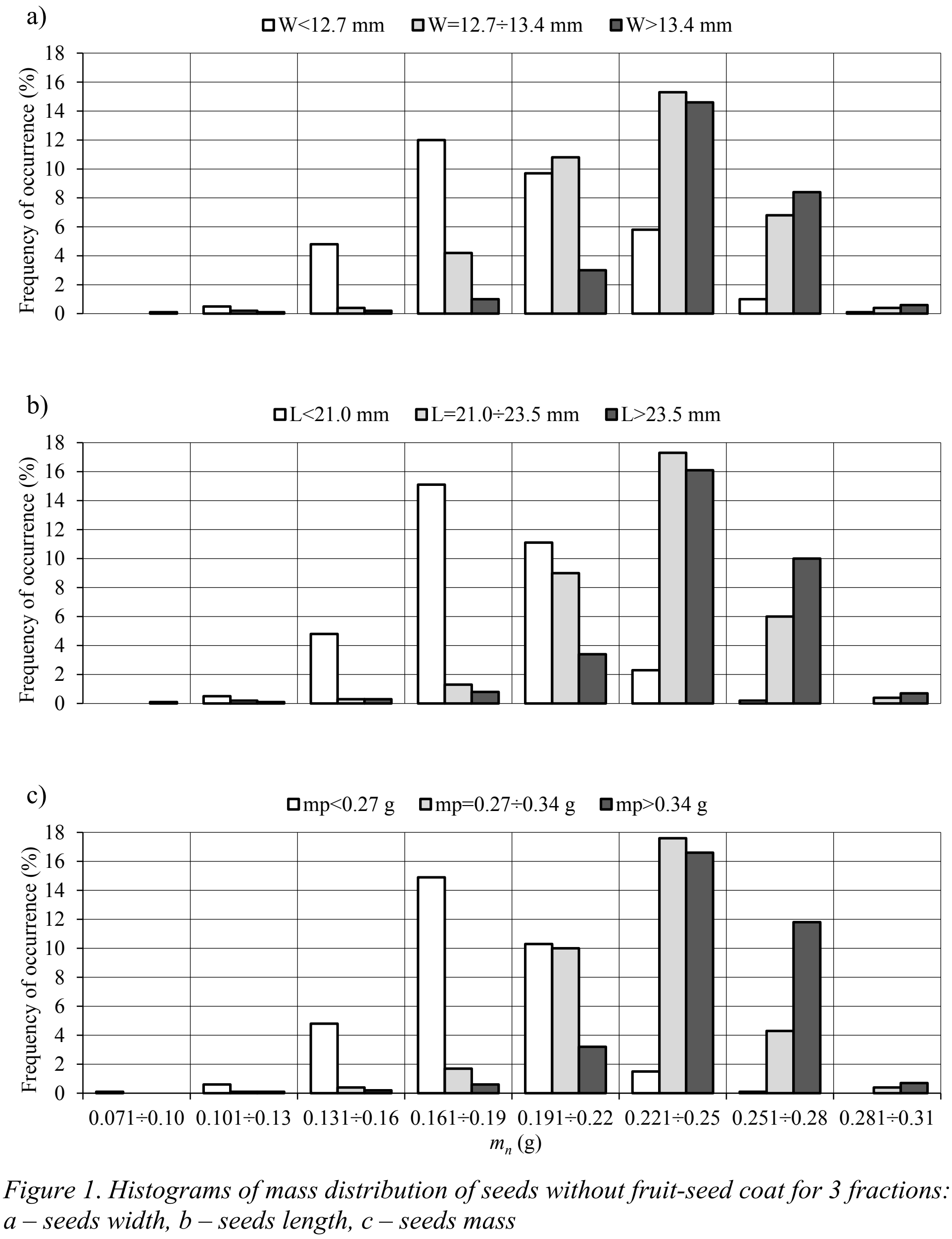

Figure 1. Histograms of mass distribution of seeds without fruit-seed coat for 3 fractions: a – seeds width, b – seeds length, c – seeds mass

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ZMIENNOŚCI I KORELACJA WYBRANYCH CECH FIZYCZNYCH PESTEK DYNI ZWYCZAJNEJ (*CUCURBITA PEPO L.*)

Streszczenie. Określono podstawowe wymiary (długość, szerokość i grubość), prędkość krytyczną unoszenia, kąt tarcia poślizgowego i masę pestek dyni zwyczajnej, pozyskanych z czterech owoców o różnej masie. Na podstawie pomiarów obliczono objętość i gęstość każdej pestki oraz jej wskaźniki sferyczności. Współzależność między badanymi cechami i wskaźnikami oceniono na podstawie testu t dla prób niezależnych, analizy wariancji, korelacji i regresji. Stwierdzono, że cechą fizyczną o największej zmienności jest masa pestek, a o najmniejszej – ich długość. Puste i pełne pestki dyni najlepiej jest rozdzielać za pomocą separatora pneumatycznego, gdzie elementem rozdzielczym jest pionowy strumienia powietrza o prędkości ok. 5 $m \cdot s^{-1}$. Przy rozdzielaniu materiału nasiennego na frakcje jakościowe można wykorzystać jako cechę rozdzielczą długość lub masę pestek. W wyniku oddzielania najmniejszej frakcji pestek można uzyskać materiał nasienny, w którym po procesie usuwania okrywy owocowo-nasiennej znajdować się będzie ok. 95% nasion dorodnych.

Słowa kluczowe: dynia, nasiona, wydzielanie, cechy fizyczne