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ASSESSMENT OF CEREAL SEED SHAPE WITH THE USE OF SPHERICITY FACTORS

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Abstract

Shape is one of the key discriminating factors in seeds. It plays a major role in seed cleaning and sorting, and it influences the bulk behavior of seeds. The shape of seeds can be described with the use of sphericity factors. In this study, the thickness, width, length and mass of principal cereal seeds (wheat, rye, barley, oats and triticale) were determined. The geometric parameters of seeds were used to calculate five sphericity factors for each seed type. The results of measurements and calculations were processed statistically by analysis of variance, correlation analysis and linear regression analysis. In the group of the analyzed cereal seeds, the lowest values were noted for sphericity factor K_5 in the range of 0.046 to 0.275, and the highest values – for sphericity factor K_3 in the range of 0.359 to 0.650. The shape of cereal seeds was mostly highly correlated with: thickness in barley seeds, width in wheat seeds, width and thickness in rye and triticale seeds, and length in oat seeds. All of the analyzed sphericity factors can be used interchangeably to describe the shape of cereal seeds, and the relationships between those factors can be described with linear equations.

Symbols

K_1 – sphericity factor describing the ratio of seed thickness to seed length,
K_2 – sphericity factor describing the ratio of seed width to seed length,
K_3 – sphericity factor describing the ratio of geometric mean diameter to seed length,
K_4, K_5 – sphericity factors describing the ratio of seed thickness and seed width to seed length,
L – seed length, mm,
T – seed thickness, mm,
W – seed width, mm.

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Introduction

Cereals are the most common crops in Poland and worldwide. Cereal seeds can be used for sowing crop plants, for energy production and, above all, as raw materials for animal feed and food production. Cereal production involves various processes, including sowing, harvest, transport, cleaning, sorting, storage and processing. A sound knowledge of the physical properties of processed materials is required at every stage of the production process and during modeling (HEBDA, MICEK 2007, ZDYBEL et al. 2009, BOAC et al. 2010, KUSIŃSKA et al. 2010, KALKAN, KARA 2011, MARKOWSKI et al. 2013, SOLOGUBIK et al. 2013).

Shape is one of the key discriminating factors in seeds, which enables to distinguish one type of seeds from another. It plays a major role in seed cleaning and sorting, and it influences the bulk behavior of seeds (seed shape determines the angle of repose). Seed shape can be described in three ways: by comparing a seed to a geometric figure, by calculating the shape factor, and with the use of virtual models (FRĄCZEK, WRÓBEL 2006). In the simplified method, the shape of a seed is compared to a geometric figure. The most common seed shapes include spherical, ellipsoid, lenticular, pyramidal and polyhedral (GROCHOWICZ 1994, FRĄCZEK, WRÓBEL 2006). More detailed evaluations of seed shape involve virtual models which are developed with the use of parametric equations or by modeling real-world objects in virtual space (JAIN, BAL 1997, MABILLE, ABECASSIS 2003, FRĄCZEK, WRÓBEL 2006, MIESZKALSKI, SOŁODUCHA 2008). Virtual models preserve shape features characteristic of a given species, but they require specialist applications and are, therefore, rarely used. The shape of seeds is generally described with the use of shape factors of varied complexity (FRĄCZEK, WRÓBEL 2006). The formulas of shape factors are based primarily on the geometric parameters of seeds. The greater the similarity between the described parameters, the more likely the shape factor is to approximate 1% or 100%. Since the value of the sphericity factor describing ideally spherical seeds and cuboid seeds is the same, FRĄCZEK and WRÓBEL (2006) proposed to describe the shape of seeds by determining the sphericity factor and the type of geometric figure which most closely resembles the analyzed seeds.

In the literature, various mathematical formulas are given for describing the sphericity factors of seeds (MOHSENIN 1986, GROCHOWICZ 1994, FRĄCZEK, WRÓBEL 2006, TYLEK 2010). For this reason, the results presented by different authors cannot always be reliably compared.

The objective of this study was to determine the range of variation in five sphericity factors of cereal seeds, to determine the effect of seed dimensions and seed mass on sphericity factors, and to determine the relationships between the analyzed sphericity factors.

Materials and Methods

The experimental material comprised seeds of primary cereals (wheat var. Nawra, rye var. Dańkowskie Złote, barley var. Skarb, oats var. Kasztan and triticale var. Atletico), harvested in north-eastern Poland. The relative moisture content of the evaluated seeds was determined on a drying scale with a 50/WH halogen lamp at: wheat – 12.8%, rye – 12.5%, barley – 12.6%, oats – 11.4% and triticale – 13.2%. The survey sampling method was used to randomly select 120 seeds from seed samples of 2 kg each. Standard error of the estimate did not exceed 0.25 mm for the three basic seed dimensions and 2.5 mg for seed mass.

Basic dimensions were determined using an MWM 2325 workshop microscope (length and width) to the nearest 0.02 mm and a thickness gauge to the nearest 0.01 mm, and seed mass was determined on a WAA 100/C/2 weighing scale to the nearest 0.1 mg. The measurements were performed according to the method described by KALINIEWICZ et al. (2011).

The shape of every type of seeds was described by determining the following sphericity factors (MOHSENIN 1986, GROCHOWICZ 1994, TYLEK 2010):

$$K_1 = \frac{T}{L} \tag{1}$$

$$K_2 = \frac{W}{L} \tag{2}$$

$$K_3 = \frac{(T \cdot W \cdot L)^{\frac{1}{3}}}{L} \tag{3}$$

$$K_4 = \frac{T + W}{2L} \tag{4}$$

$$K_5 = \frac{T \cdot W}{L^2} \tag{5}$$

The results of measurements and calculations were processed in the Statistica 10.0 program by one-way ANOVA, correlation analysis and linear regression analysis (RABIEJ 2012) at a significance level of 0.05.

Results and Discussion

The physical parameters of the analyzed cereal seeds are presented in Table 1. The average seed mass of the analyzed cereal varieties was compared with that of other cereal varieties (MABILLE, ABECASSIS 2003, HEBDA, MICEK 2005, 2007, KOCIUBA et al. 2007, ZDYBEL et al. 2009, CACAK-PIETRZAK et al. 2010, CHRZĄSTEK et al. 2010) to reveal that rye seeds were characterized by low plumpness, wheat, barley and triticale seeds – by average plumpness, and oat seeds – by high plumpness. Oat seeds were longest, and wheat seeds were shortest. Thickness and width were highest in barley and lowest in rye seeds. A comparison of the average dimensions of seeds of the analyzed cereal varieties with those of other varieties (MABILLE, ABECASSIS 2003, SEGIT et al. 2003, HEBDA, MICEK 2005, 2007, SADOWSKA, ŻABIŃSKI 2009, ZDYBEL et al. 2009, BOAC et al. 2010, KALKAN, KARA 2011, MARKOWSKI et al. 2013, SOLOGUBIK et al. 2013) revealed similar relationships to those noted in an analysis of seed mass. A comparison of the dimensions of seeds of the same wheat variety demonstrated that the analyzed material was characterized by higher plumpness than that studied by GEODECKI and GRUNDAS (2003).

Table 1

Statistical parameters of the distribution of the physical characteristics of cereal seeds

Seed type	Physical parameter	Value of parameter			Standard deviation
		min.	max	mean	
wheat	thickness [mm]	2.44	3.34	2.87	0.209
	width [mm]	2.52	3.95	3.29	0.305
	length [mm]	5.59	8.29	6.73	0.394
	mass [mg]	26.7	61.4	44.41	8.908
Rye	thickness [mm]	1.75	2.95	2.39	0.245
	width [mm]	1.83	3.43	2.65	0.276
	length [mm]	5.40	9.13	7.49	0.678
	mass [mg]	10.9	46.8	28.67	6.937
Barley	thickness [mm]	2.11	3.38	2.87	0.223
	width [mm]	2.92	4.40	3.84	0.294
	length [mm]	7.37	10.65	9.03	0.653
	mass [mg]	23.4	66.4	45.29	8.620
Oats	thickness [mm]	2.05	2.95	2.55	0.151
	width [mm]	2.44	3.66	3.15	0.249
	length [mm]	7.34	13.70	10.39	1.201
	mass [mg]	16.0	54.4	38.57	8.023
Triticale	thickness [mm]	1.88	3.41	2.70	0.331
	width [mm]	2.07	3.96	3.23	0.382
	length [mm]	5.91	9.27	7.57	0.602
	mass [mg]	14.9	64.5	40.04	11.670

The statistical distribution of sphericity factors characterizing seeds of the analyzed cereal varities is presented in Table 2. The highest mean values of sphericity factors were noted in wheat seeds, and the lowest – in oat seeds. Sphericity factor K_1 ranged from 0.185 to 0.488. Statistically significant differences in the values of K_1 were not observed only in rye and barley seeds. In seeds of rye var. Dańkowskie Złote, the value of factor K_1 was nearly identical to that reported for this variety by FRĄCZEK and WRÓBEL (2006). In seeds of the analyzed cereal varieties, the values of factor K_1 were similar to those noted in other varieties. Considerable similarities were observed in relation to seeds of wheat var. Nawra and Roma (FRĄCZEK, WRÓBEL 2006), seeds of barley var. Skarb, Rastik (SADOWSKA, ŻABIŃSKI 2009) and Rodion (HEBDA, MICEK 2005), and seeds of oat var. Kasztan and Dukat (HEBDA, MICEK 2005). The mean value of the sphericity factor for seeds of wheat var. Nawra was similar to that reported in lentils var. Anita and beans var. Atena (FRĄCZEK, WRÓBEL 2006).

Table 2

Statistical parameters of the distribution of the sphericity factors of cereal seeds

Seed type	Sphericity factor	Value of sphericity factor			Standard deviation
		min.	max	mean	
Wheat	K_1	0.368	0.488	0.426^a	0.025
	K_2	0.375	0.601	0.489^a	0.038
	K_3	0.520	0.650	0.592^a	0.024
	K_4	0.375	0.529	0.458^a	0.028
	K_5	0.141	0.275	0.209^a	0.025
Rye	K_1	0.252	0.437	0.319^c	0.028
	K_2	0.284	0.456	0.354^c	0.032
	K_3	0.425	0.579	0.483^d	0.026
	K_4	0.277	0.441	0.337^d	0.027
	K_5	0.077	0.194	0.114^d	0.019
Barley	K_1	0.256	0.393	0.318^c	0.027
	K_2	0.358	0.496	0.426^b	0.031
	K_3	0.451	0.573	0.513^c	0.025
	K_4	0.307	0.436	0.372^c	0.027
	K_5	0.092	0.188	0.136^c	0.020
Oats	K_1	0.185	0.361	0.248^d	0.029
	K_2	0.244	0.381	0.306^d	0.028
	K_3	0.359	0.507	0.423^e	0.027
	K_4	0.217	0.361	0.277^e	0.027
	K_5	0.046	0.130	0.076^e	0.015
Triticale	K_1	0.250	0.433	0.358^b	0.035
	K_2	0.278	0.524	0.427^b	0.040
	K_3	0.411	0.596	0.534^b	0.032
	K_4	0.264	0.463	0.392^b	0.034
	K_5	0.069	0.211	0.154^b	0.027

a, *b*, *c*, *d*, *e* – different letters denote statistically significant differences between the values of a given sphericity factor in the analyzed cereal species.

The value of sphericity factor K_2 ranged from 0.244 to 0.601. Similar values of K_2 (statistically non-significant differences) were observed in barley and triticale seeds. The values of K_2 were highly similar in seeds of the following cereal varieties:

– wheat var. Nawra – wheat var. Roma (FRĄCZEK, WRÓBEL 2006) and Ceralio (MARKOWSKI et al. 2013),

– rye var. Dańkowskie Złote – rye var. Amilo (ZDYBEL et al. 2009),

– barley var. Skarb – barley var. Rastik (SADOWSKA, ŻABIŃSKI 2009).

The value of factor K_2 noted in this study was practically identical to that determined by FRĄCZEK and WRÓBEL (2006) who analyzed the shape of seeds of the same rye variety.

In the literature, K_3 is the most widely used sphericity factor. In the group of the analyzed factors, K_3 was characterized by the highest values in the range of 0.359 to 0.650. All of the analyzed cereal species differed significantly in their values of K_3. The value of K_3 describing seeds of wheat var. Nawra was similar to that reported in wheat var. Korweta (MARKOWSKI et al. 2013) and Bayraktar-2000 (KALKAN, KARA 2011) and in seeds of the African star apple (OYELADE et al. 2005). In seeds of barley var. Skarb, the value of factor $K3$ was similar to that reported in seeds of barley var. Scarlett (SOLOGUBIK et al. 2013), blond psyllium (AHMADI et al. 2012) and flaxseed (PRADHAN et al. 2010). In seeds of oat var. Kasztan, the value of K_3 was similar to that reported in edible squash (PAKSOY, AYDIN 2004).

Sphericity factor K_4 ranged from 0.217 (oat seeds) to 0.529 (wheat seeds). Seeds of all cereal species analyzed in this study differed significantly in values of K_4. Similar relationships between seed types were observed in respect of K_5 which was characterized by the lowest values in the group of the evaluated sphericity factors. K_5 ranged from 0.046 (oat seeds) to 0.275 (wheat seeds).

An analysis of linear correlations between physical parameters (dimensions and mass) and sphericity factors (Tab. 3) revealed that seed shape was most highly correlated with the following parameters:

– thickness in barley seeds,

– width in wheat seeds,

– width and thickness in rye and triticale seeds,

– length in oat seeds.

Parameters which had a negligible effect on sphericity factors were: length in wheat and triticale seeds, width and thickness in oat seeds, and mass in rye seeds. In all cases, the value of the sphericity factor increased with seed thickness and decreased with a rise in seed length. The above results from the applied formulas, and it indicates that the dimensions of cereal seeds do not increase proportionally with an increase in their plumpness. The relationships between the analyzed sphericity factors and physical parameters were similar, which suggests that the evaluated factors can be applied interchangeably to cereal seeds. Nonetheless, the seed shape of other cereal species justifies the use of factors whose formulas account for all three dimensions, namely factors K_3, K_4 and K_5.

Table 3

Coefficients of linear correlation between selected physical parameters and sphericity factors of cereal seeds

Seed type	Physical parameter	Correlation coefficient for:				
		K_1	K_2	K_3	K_4	K_5
Wheat	thickness	**0.609**	**0.421**	**0.560**	**0.549**	**0.557**
	width	**0.370**	**0.781**	**0.670**	**0.685**	**0.670**
	length	**-0.222**	-0.083	-0.159	-0.153	-0.159
	mass	**0.356**	**0.543**	**0.514**	**0.520**	**0.515**
Rye	thickness	**0.543**	**0.246**	**0.440**	**0.427**	**0.429**
	width	**0.244**	**0.564**	**0.446**	**0.456**	**0.433**
	length	**-0.332**	**-0.329**	**-0.362**	**-0.364**	**-0.371**
	mass	**0.181**	0.127	0.174	0.168	0.159
Barley	thickness	**0.611**	**0.474**	**0.579**	**0.566**	**0.569**
	width	**0.272**	**0.533**	**0.415**	**0.433**	**0.408**
	length	**-0.505**	**-0.421**	**-0.489**	**-0.484**	**-0.494**
	mass	**0.323**	**0.372**	**0.367**	**0.368**	**0.357**
Oats	thickness	0.154	0.010	0.096	0.088	0.103
	width	**-0.383**	0.097	-0.175	-0.154	**-0.190**
	length	**-0.851**	**-0.734**	**-0.853**	**-0.847**	**-0.845**
	mass	**-0.350**	-0.106	**-0.251**	**-0.245**	**-0.267**
Triticale	thickness	**0.761**	**0.508**	**0.697**	**0.682**	**0.691**
	width	**0.515**	**0.748**	**0.690**	**0.697**	**0.681**
	length	-0.032	-0.044	-0.036	-0.042	-0.044
	mass	**0.538**	**0.518**	**0.579**	**0.575**	**0.576**

Values in bold denote statistically significant correlations.

All of the analyzed sphericity factors were closely correlated. The above can be inferred by analyzing the coefficients of determination in regression equations of pairs of values (Tab. 4). In the combined population of seed batches representing five cereal species, the values of the coefficient of determination were very high, ranging from 0.772 for the relationship between K_1 and K_2 to 0.998 for the relationship between K_3 and K_4. The equations were applied to biological material, and they can be used to convert sphericity factors when only selected factors are given. This approach can be used to compare the shape of cereal seeds from various batches.

Table 4

Relationships between sphericity factors and other parameters of cereal seeds

Equation	Coefficient of determination R^2	Standard error of the estimate
$K_1 = 0.790\ K_2 + 0.018$	0.772	0.031
$K_1 = 1.011\ K_3 - 0.181$	0.942	0.016
$K_1 = 0.943\ K_4 - 0.012$	0.933	0.017
$K_1 = 1.286\ K_5 + 0.157$	0.938	0.016
$K_2 = 0.978\ K_1 + 0.074$	0.772	0.034
$K_2 = 1.121\ K_3 - 0.170$	0.935	0.018
$K_2 = 1.057\ K_4 + 0.012$	0.946	0.017
$K_2 = 1.418\ K_5 + 0.205$	0.921	0.020
$K_3 = 0.931\ K_1 + 0.198$	0.942	0.015
$K_3 = 0.834\ K_2 + 0.175$	0.935	0.016
$K_3 = 0.936\ K_4 - 0.165$	0.998	0.003
$K_3 = 1.262\ K_5 + 0.335$	0.981	0.008
$K_4 = 0.989\ K_1 + 0.037$	0.933	0.017
$K_4 = 0.895\ K_2 + 0.009$	0.946	0.015
$K_4 = 1.066\ K_3 - 0.176$	0.998	0.003
$K_4 = 1.352\ K_5 + 0.181$	0.988	0.007
$K_5 = 0.729\ K_1 - 0.106$	0.938	0.012
$K_5 = 0.649\ K_2 - 0.122$	0.921	0.014
$K_5 = 0.778\ K_3 - 0.258$	0.981	0.007
$K_5 = 0.731\ K_4 - 0.131$	0.988	0.005

Conclusions

1. Only minor similarities in the value of the sphericity factor, calculated based on two dimensions, were determined in rye and barley seeds and in barley and triticale seeds. The remaining comparisons revealed statistically significant differences. In the analyzed cereal seeds, the lowest values were noted for sphericity factor K_5 in the range of 0.046 to 0.275, and the highest values – for sphericity factor K_3 in the range of 0.359 to 0.650.

2. Sphericity factors were influenced mostly by variations in seed dimensions, whereas seed shape was most highly correlated with: thickness in barley seeds, width in wheat seeds, width and thickness in rye and triticale seeds, and length in oat seeds.

3. All of the presented sphericity factors can be used interchangeably to describe the shape of cereal seeds. Sphericity factors are closely correlated, therefore, they can be converted with the use of simple linear equations characterized by high values of the coefficient of determination. Sphericity factor K_3, which incorporates all three seed dimensions, delivers the most accurate results, and it is most frequently used in research papers.

References

AHMADI R., KALBASI-ASHTARI A., GHARIBZAHEDI S.M.T. 2012. *Physical properties of psyllium seed*. International Agrophysics, 26: 91–93.

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*. Transactions of the ASABE, 53(4): 1201–1216.

CACAK-PIETRZAK G., SUŁEK A., GONDEK E., SUŁEK A. 2010. *Plonowanie oraz cechy jakościowe ziarna nowych odmian pszenicy jarej w zależności od poziomu nawożenia azotem*. Zeszyty Problemowe Postępów Nauk Rolniczych, 553: 11–19.

CHRZĄSTEK M., KRUK K., WÓJTOWICZ E. 2010. *Zmienność mieszańców międzygatunkowych owsa pod względem niektórych cech plonotwórczych wiechy głównej*. Zeszyty Problemowe Postępów Nauk Rolniczych, 556: 357–365.

FRĄCZEK J., WRÓBEL M. 2006. *Metodyczne aspekty oceny kształtu nasion*. Inżynieria Rolnicza, 12: 155–163.

GEODECKI M., GRUNDAS S. 2003. *Charakterystyka cech geometrycznych pojedynczych ziarniaków pszenicy ozimej i jarej*. Acta Agrophysica, 2(3): 531–538.

GREŃ J. 1984. *Statystyka matematyczna. Modele i zadania*. Wyd. PWN, Warszawa.

GROCHOWICZ J. 1994. *Maszyny do czyszczenia i sortowania nasion*. Wyd. AR, Lublin.

HEBDA T., MICEK P. 2005. *Zależności pomiędzy właściwościami geometrycznymi ziarna zbóż*. Inżynieria Rolnicza, 6: 233–241.

HEBDA T., MICEK P. 2007. *Cechy geometryczne ziarna wybranych odmian zbóż*. Inżynieria Rolnicza, 5(93): 187–193.

JAIN R.K., BAL S. 1997. *Properties of pearl millet*. Journal of Agricultural Engineering Research, 66: 85–91.

KALINIEWICZ Z., GRABOWSKI A., LISZEWSKI A., FURA S. 2011. *Analysis of correlations between selected physical attributes of Scots pine seeds*. Technical Sciences, 14(1): 13–22.

KALKAN F., KARA M. 2011. *Handling, frictional and technological properties of wheat as affected by moisture content and cultivar*. Powder Technology, 213: 116–122.

KOCIUBA W., KRAMEK A., DOLIŃSKI R. 2007. *Porównanie wartości cech użytkowych krajowych odmian pszenżyta ozimego zarejestrowanych w latach 1982-2003*. Zeszyty Problemowe Postępów Nauk Rolniczych, 517: 379–387.

KUSIŃSKA E., KOBUS Z., NADULSKI R. 2010. *Wpływ wilgotności na właściwości fizyczne i geometryczne ziarna żyta odmiany Słowiańskie*. Inżynieria Rolnicza, 4(122): 151–156.

MABILLE F., ABECASSIS J. 2003. *Parametric modelling of wheat grain morphology: a new perspective*. Journal of Cereal Science, 37: 43–53.

MARKOWSKI M., ŻUK-GOŁASZEWSKA K., KWIATKOWSKI D. 2013. *Influence of variety on selected physical and mechanical properties of wheat*. Industrial Crops and Product, 47: 113–117.

MIESZKALSKI L., SOŁODUCHA H.K. 2008. *Metody modelowania zbioru brył nasion*. Postępy Techniki Przetwórstwa Spożywczego, 1: 39–44.

MOHSENIN N.N. 1986. *Physical properties of plant and animal materials*. Gordon and Breach Science Public, New York.

OYELADE O.J., ODUGBENRO P.O., ABIOYE A.O., RAJIN.L. 2005. *Some physical properties of African star apple (Chrysophyllum alibidum) seeds*. Journal of Food Engineering, 67: 435–440.

PAKSOY M., AYDIN C. 2004. *Some physical properties of edible squash (Cucurbita pepo L.) seeds*. Journal of Food Engineering, 65: 225–231.

PRADHAN R.C., MEDA V., NAIK S.N., TABIL L. 2010. *Physical properties of Canadian grown flaxseed in relation to its processing*. International Journal of Food Properties, 13: 732–743.

RABIEJ M. 2012. *Statystyka z programem Statistica*. Wyd. Helion, Gliwice.

SADOWSKA U., ŻABIŃSKI A. 2009. *Niektóre właściwości fizyczne ziarniaków jęczmienia nagoziarnistego uprawianego w mieszance z soczewicą jadalną*. Inżynieria Rolnicza, 6(115): 229–236.

SEGIT Z., SZWED G., SZWED-URBAŚ K. 2003. *Uszkodzenia ziarniaków pszenicy twardej w wyniku obciążeń dynamicznych*. Acta Agrophysica, 2(4): 841–849.

SOLOGUBIK C.A., CAMPAÑONE L.A., PAGANO A.M., GELY M.C. 2013. *Effect of moisture content on some physical properties of barley*. Industrial Crops and Products, 43: 762–767.

TYLEK P. 2010. *Fizyczne i biologiczne aspekty mechanicznej separacji nasion buka zwyczajnego (Fagus sylvatica L.)*. Zeszyty Naukowe Uniwersytetu Rolniczego im. Hugona Kołłątaja w Krakowie, Rozprawy, 467(344).

ZDYBEL A., GAWŁOWSKI S., LASKOWSKI J. 2009. *Wpływ wilgotności na wybrane właściwości fizyczne ziarna żyta*. Acta Agrophysica, 14(1): 243–255.