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DETERMINATION OF SHAPE FACTORS AND VOLUME COEFFICIENTS OF SEEDS FROM SELECTED CONIFEROUS TREES

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Abstract

The thickness, width and length of seeds from selected coniferous trees was measured. The obtained data was used to determine six shape factors (as proposed by Grochowicz, Mohsenin, Donev and Wróbel). The seeds were assigned nine simple geometric shapes, and the total volume of seeds from a given tree species was compared using a pycnometer. Based on the results, a geometric model of seed volume was selected for every analyzed species. It was concluded that the shape of seeds from coniferous trees can be described with the application of shape factors proposed by Mohsenin, Donev and Wróbel, used interchangeably or collectively. The volume of seeds from coniferous trees can be modeled with the use of an ellipsoid for Scots pine, European black pine, Norway spruce and English yew seeds, and a double right quadrangular pyramid for silver fir and Douglas-fir seeds.

Symbols:

d_w, d_z – equivalent diameter of basic seed dimensions, mm,
k – coefficient of seed volume,
k_{Mi} – volume coefficient of the i^{th} seed model,
K_m, K_w – Grochowicz's shape factors,
S – standard deviation of trait,
S_n – Mohsenin's shape factor,
T, W, L – seed thickness, width and length, mm,
V – seed volume, mm^3,
V_{Mi} – volume of the i^{th} geometric model, mm^3,
V_p – total volume of seed sample, mm^3,
x – average value of trait,
$x_{\max}$ – maximum value of trait,
$x_{\min}$ – minimum value of trait,
α, β – Donev's shape factors,
α_w – Wróbel's shape factor.

Introduction

The seeds of coniferous trees are characterized by considerable variation in dimensions. Their size is determined by the type of habitat and soil on which trees grow, atmospheric conditions during cone and seed development, genetic traits, geographic location of trees and the position of cones in the tree crown (MURAT 2002, *Nasiennictwo leśnych drzew...* 1995, SIVACIOGLU, AYAN 2010, TURNA, GÜNEY 2009). Shape is also a distinguishing feature of seeds. The above parameters are used in the process of cleaning and sorting seeds (GROCHOWICZ 1994).

The shape of seeds is described with the use of corresponding shape factors. In a simplified evaluation method, the geometric shape most closely resembling the analyzed seed is chosen (FRĄCZEK, WRÓBEL 2006). Detailed evaluations rely on virtual models which are developed with the use of parametric equations or by modeling real objects in virtual space (JAIN, BAL 1997, FRĄCZEK, WRÓBEL 2006, 2009, MABILLE, ABECASSIS 2003, MIESZKALSKI, SOŁODUCHA 2008). The above methods preserve shape features characteristic of a given species, nevertheless, they require specialist applications, and they are not popularly used.

The objective of this study was to determine the values of shape factors describing seeds of selected coniferous tree species, to analyze correlations between those values, and to select simple geometric shapes that best model seed volume.

Materials and Methods

The experimental materials consisted of seeds from the following coniferous tree species: Scots pine, European black pine, Norway spruce, European larch, silver fir, Douglas-fir and English yew (Fig. 1). The seeds of the Scots pine, European black pine, Norway spruce and European larch were harvested from the following stands entered into the National Register of Approved Basic Material:

a) MP/3/41008/05 (category of forest reproductive material – qualified, type – plantation, region of provenance – 253, municipality – Mały Płock (22.04°E, 53.18°N), forest habitat – fresh mixed coniferous forest, age – 15, 20 years),

b) MP/3/41225/05 (category of forest reproductive material – qualified, type – plantation, region of provenance – 157, municipality – Gardeja (18.54°E, 53.40°N), forest habitat – fresh mixed broadleaved forest, age – 19 years),

c) MP/1/46879/06 (category of forest reproductive material – source identified, type – tree stand, region of provenance – 205, municipality – Purda (20.41°E, 53.39°N), forest habitat – fresh mixed coniferous forest, age – 86 years),

d) MP/2/30944/05 (category of forest reproductive material – selected, type – tree stand, region of provenance – 202, municipality – Kowale Oleckie (22.15°E, 54.06°N), forest habitat – fresh mixed broadleaved forest, age – 129 years).

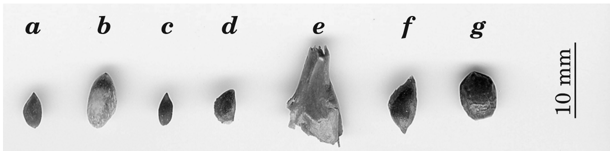

Fig. 1. Seeds of coniferous trees: *a* – Scots pine, *b* – European black pine, *c* – Norway spruce, *d* – European larch, *e* – silver fir, *f* – Douglas-fir, *g* – English yew

The seeds of the remaining species were supplied by Florpak Sp. z o.o., Branch in Młynki, Końskowola. The seeds were collected from the following areas:

a) silver fir – commune Mykanów (19.09°E, 50.59°N),

b) Douglas-fir – commune Ujsoły (19.11°E, 49.27°N),

c) English yew – commune Mogilno (17.96°E, 52.65°N).

To determine the dimensions of each seed species, the material was spread on a table and divided by halving (*Nasiennictwo leśnych drzew...* 1995) to obtain samples of more than 100 seeds each. The above method produced samples with the following size: Scots pine – 106 seeds, European black pine – 124, Norway spruce – 113, European larch – 109, silver fir – 122, Douglas-fir – 121, English yew – 125.

Seed dimensions were determined using the MWM 2325 workshop microscope and a dial indicator device, as described by Kaliniewicz (KALINIEWICZ et al. 2011).

The following shape factors were calculated:

a) Grochowicz's shape factors (1994):

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

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

b) Mohsenin's shape factor (1986):

$$S_n = \sqrt[3]{\frac{T \cdot W}{L^2}} = \frac{(T \cdot W \cdot L)^{\frac{1}{3}}}{L} \tag{3}$$

c) Donev's shape factors (DONEV et al. 2004):

$$\alpha = \frac{L}{T} \tag{4}$$

$$\beta = \frac{W}{T} \tag{5}$$

d) Wróbel's shape factor (2006):

$$\alpha_w = \frac{2 \cdot L}{T + W} \tag{6}$$

The correlations between Donev's and Wróbel's shape factors were determined on the assumption that the axis of rotation and seed length overlap, and the remaining two dimensions correspond to seed width and thickness.

The volume of all seeds in the sample (V_p) was calculated using a 25 cm^3 pycnometer equipped with a thermometer and a capillary tube. Based on seed volume and dimensions, the value of the seed volume coefficient was calculated using the below formula:

$$k = \frac{V_p}{\Sigma T \cdot W \cdot L} \tag{7}$$

We assumed that the shape of seeds could be modeled by geometric shapes whose volume is equivalent to the volume of the analyzed seeds. The following geometric models were considered (Fig. 2): sphere ($M1$), cylinder ($M2$), spheroid ($M3$), ellipsoid ($M4$), cuboid ($M5$), right triangular prism ($M6$), double cone ($M7$), double quadrangular pyramid ($M8$) and double triangular pyramid ($M9$). The volume of the above geometric shapes was determined based on the following general formulas:

$$V_{M1} = \frac{\pi \cdot d_w^3}{6} \tag{8}$$

$$V_{M2} = \frac{\pi \cdot d_z^2 \cdot L}{4} \tag{9}$$

$$V_{M3} = \frac{\pi \cdot d_z^2 \cdot L}{6} \quad (10)$$

$$V_{M4} = \frac{\pi \cdot T \cdot W \cdot L}{6} \quad (11)$$

$$V_{M5} = T \cdot W \cdot L \quad (12)$$

$$V_{M6} = \frac{T \cdot W \cdot L}{2} \quad (13)$$

$$V_{M7} = \frac{\pi \cdot d_z^2 \cdot L}{12} \quad (14)$$

$$V_{M8} = \frac{T \cdot W \cdot L}{3} \quad (15)$$

$$V_{M9} = \frac{T \cdot W \cdot L}{6} \quad (16)$$

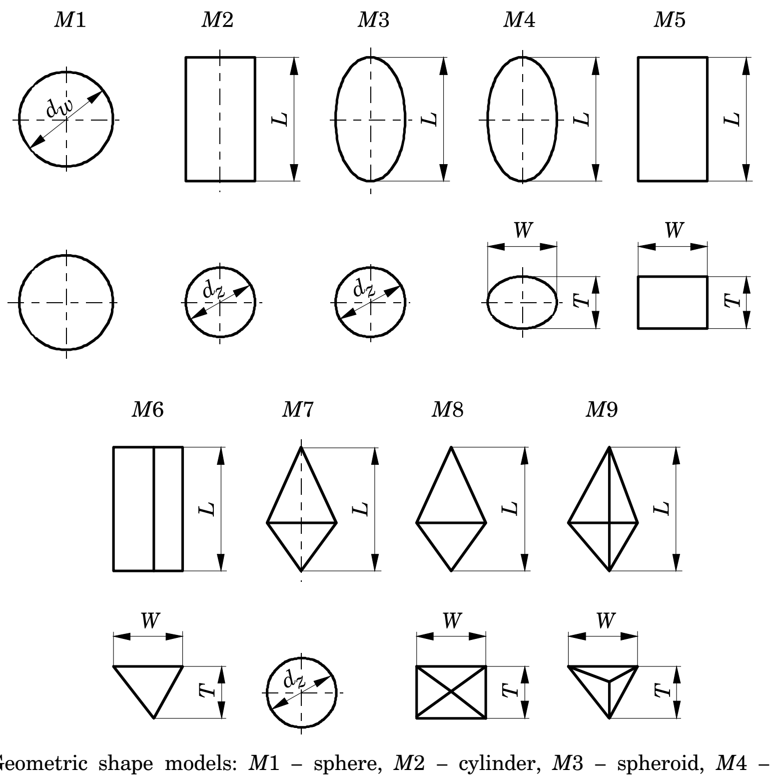

Fig. 2. Geometric shape models: $M1$ – sphere, $M2$ – cylinder, $M3$ – spheroid, $M4$ – ellipsoid, $M5$ – cuboid, $M6$ – right triangular prism, $M7$ – double cone, $M8$ – double quadrangular pyramid, $M9$ – double triangular pyramid

Geometric shapes were selected depending on whether their volume could be calculated with the use of three basic geometric dimensions: the thickness, width and length of modeled particles. Equivalent diameters in models $M1$, $M2$, $M3$ and $M7$ were determined based on the below formulas (GROCHOWICZ 1994):

$$d_w = \frac{T + W + L}{3} \tag{17}$$

$$d_z = \frac{T + W}{2} \tag{18}$$

In models $M7$, $M8$ and $M9$, the location of the largest cross-section was not significant because it did not affect seed volume. In extreme cases, the above models can take on the form of an individual shape, such as a cone, a quadrangular pyramid or a triangular pyramid.

The volume coefficients of the geometric models of different seed species were determined using the following formula:

$$k_{Mi} = \frac{V_{Mi}}{T \cdot W \cdot L} \tag{19}$$

The results were processed statistically by analysis of variance and correlation analysis, using Winstat and Statistica software.

Results and Discussion

The statistical parameters describing the distribution of seed dimensions are presented in Table 1. The seeds of the English yew were characterized by the lowest dimensional variation (coefficient of variation did not exceed 7.3). The highest coefficient of variation was observed with regard to the width of silver fir seeds (15.5). The range of variations corresponds to the dimensional characteristics of seeds harvested in Poland (CZERNIK 1983, *Nasiennictwo leśnych drzew...* 1995, TYLEK 1998, 2004, 2005). The thickness of seeds from various tree species varied between 0.95 mm (European larch) to 4.78 mm (English yew), seed width – from 1.76 mm (European larch) to 8.01 mm (silver fir), and length – between 3.10 mm (European larch) to 14.18 (silver fir). Based on their average dimensions, seeds were classified in ascending order:

a) seed thickness – European larch, Scots pine, Norway spruce, Douglas-fir, European black pine, silver fir, European yew,

b) seed width – Norway spruce, Scots pine, European larch, European black pine, Douglas-fir, English yew, silver fir,

c) seed length – Norway spruce, Scots pine, European larch, European black pine, English yew, Douglas-fir, silver fir.

Table 1

Statistical parameters describing the distribution of seed dimensions

Seed species	Dimension	x_{min}	x_{max}	x	S	V_s
Scots pine	T	1.09	1.80	1.45^f	0.142	9.78
	W	1.88	3.00	2.50^e	0.241	9.63
	L	3.22	5.31	4.19^e	0.416	9.92
European black pine	T	1.92	3.19	2.46^c	0.214	8.69
	W	2.37	4.47	3.43^c	0.385	11.22
	L	4.83	8.36	6.46^c	0.582	9.00
Norway spruce	T	1.13	1.92	1.53^e	0.149	9.70
	W	1.77	3.01	2.25^f	0.260	11.57
	L	3.21	5.39	4.15^e	0.439	10.59
European larch	T	0.95	1.82	1.37^g	0.156	11.37
	W	1.76	3.34	2.62^d	0.325	12.38
	L	3.10	5.38	4.36^d	0.528	12.10
Silver fir	T	2.17	4.24	3.22^b	0.393	12.23
	W	3.53	8.01	5.53^a	0.857	15.50
	L	5.89	14.18	10.82^a	1.123	10.38
Douglas-fir	T	1.44	2.52	1.83^d	0.170	9.29
	W	2.80	4.63	3.49^c	0.346	9.91
	L	5.24	8.60	6.93^b	0.624	9.00
English yew	T	3.45	4.78	4.05^a	0.295	7.29
	W	3.64	5.49	4.67^b	0.315	6.74
	L	5.55	7.62	6.62^c	0.416	6.28

$^{a, b, c, d, e, f, g}$ – different lowercase letters in the superscript indicate significant differences at a level of 0.05
Source: own calculations

The average values of seed dimensions reported in this study are similar to those cited in literature (BURACZYK 2010, CZERNIK 1983, *Nasiennictwo leśnych drzew...* 1995, SIVACIOGLU, AYAN 2010, TYLEK 1998). An analysis of variance revealed significant differences between the dimensions of the analyzed seed species. Significant differences were not observed only with regard to the width of European black pine and Douglas-fir seeds, the length of Scots pine and Norway spruce seeds, and the length of European black pine and English yew seeds.

The statistical parameters describing the distribution of seed shape factors are shown in Table 2. The lowest spread of shape factor values was noted for S_n in all cases, and the highest spread was reported in respect of:

a) shape factor K_m – Norway spruce and English yew seeds,

b) shape factor K_w – Scots pine and European larch seeds,

c) shape factor β – European black pine, silver fir and Douglas-fir seeds.

Table 2

Statistical parameters describing the distribution of seed shape factors

Seed species	Shape factor	x_{min}	x_{max}	x	S	V_s
Scots pine	K_m	0.385	0.860	0.600^{b}	0.063	10.47
	K_w	0.250	0.512	0.349^{d}	0.042	11.97
	S_n	0.458	0.761	0.593^{b}	0.041	6.97
	α	1.952	4.008	2.910^{d}	0.346	11.89
	β	1.413	2.304	1.730^{b}	0.145	8.40
	α_w	1.457	3.151	2.131^{d}	0.222	10.42
European black pine	K_m	0.315	0.686	0.533^{c}	0.059	10.97
	K_w	0.281	0.507	0.383^{b}	0.043	11.18
	S_n	0.453	0.690	0.588^{b}	0.037	6.35
	α	1.971	3.557	2.646^{e}	0.300	11.32
	β	1.019	2.117	1.404^{d}	0.167	11.87
	α_w	1.732	3.273	2.204^{c}	0.222	10.07
Norway spruce	K_m	0.379	0.790	0.547^{c}	0.075	13.75
	K_w	0.296	0.454	0.371^{c}	0.037	9.95
	S_n	0.490	0.690	0.587^{b}	0.041	7.01
	α	2.201	3.383	2.719^{e}	0.265	9.75
	β	1.142	1.983	1.475^{c}	0.165	11.16
	α_w	1.677	2.890	2.204^{c}	0.239	10.85
European larch	K_m	0.478	0.929	0.604^{b}	0.066	10.93
	K_w	0.229	0.423	0.316^{e}	0.038	12.04
	S_n	0.493	0.732	0.575^{c}	0.038	6.54
	α	2.365	4.368	3.205^{c}	0.375	11.71
	β	1.450	2.432	1.926^{a}	0.223	11.58
	α_w	1.480	2.742	2.192^{c}	0.201	9.19
Silver fir	K_m	0.288	0.956	0.515^{d}	0.089	17.25
	K_w	0.181	0.535	0.299^{f}	0.041	13.61
	S_n	0.414	0.800	0.534^{d}	0.044	8.30
	α	1.870	5.539	3.398^{b}	0.447	13.17
	β	1.017	2.964	1.741^{b}	0.323	18.56
	α_w	1.342	3.541	2.495^{b}	0.313	12.53
Douglas-fir	K_m	0.373	0.734	0.506^{d}	0.053	10.44
	K_w	0.199	0.377	0.266^{g}	0.032	12.02
	S_n	0.430	0.627	0.512^{e}	0.032	6.21
	α	2.655	5.036	3.805^{a}	0.445	11.68
	β	1.512	2.660	1.918^{a}	0.237	12.37
	α_w	1.869	3.413	2.610^{a}	0.234	8.97
English yew	K_m	0.549	0.886	0.708^{a}	0.065	9.14
	K_w	0.502	0.776	0.614^{a}	0.051	8.39
	S_n	0.659	0.872	0.757^{a}	0.041	5.37
	α	1.306	1.992	1.640^{f}	0.135	8.22
	β	1.000	1.319	1.155^{e}	0.078	6.76
	α_w	1.226	1.870	1.523^{e}	0.123	8.08

$^{a, b, c, d, e, f, g}$ – different lowercase letters in the superscript indicate significant differences at a level of 0.05
Source: own calculations

The investigated seed species were classified in ascending order based on the average values of seed shape factors:

a) shape factor K_m – Douglas-fir, silver fir, European black pine, Norway spruce, Scots pine, European larch, English yew,

b) shape factor K_w – Douglas-fir, silver fir, European larch, Scots pine, Norway spruce, European black pine, English yew,

c) shape factor S_n – Douglas-fir, silver fir, European larch, European black pine, Norway spruce, Scots pine, English yew,

d) shape factor α – English yew, European black pine, Norway spruce, Scots pine, European larch, silver fir, Douglas-fir,

e) shape factor β – English yew, European black pine, Norway spruce, Scots pine, silver fir, Douglas-fir, European larch,

f) shape factor α_w – English yew, Scots pine, European larch, Norway spruce, European black pine, silver fir, Douglas-fir.

The average values of shape factors K_m and K_w for the seeds of Scots pine, Norway spruce, European larch and silver fir are comparable with those reported by CZERNIK (1983) and TYLEK (1998). Homogeneous groups (showing no significant differences between the average values of the analyzed factors) were obtained for the following seed species:

a) shape factor K_m – Scots pine and European larch, European black pine and Norway spruce, silver fir and Douglas-fir,

b) shape factor K_w – deficiency,

c) shape factor S_n – Scots pine, European black pine and Norway spruce,

d) shape factor α – European black pine and Norway spruce,

e) shape factor β – European larch and Douglas-fir, Scots pine and silver fir,

f) shape factor α_w – European black pine, Norway spruce and European larch.

In this experiment, we also set out to determine the shape factor or a group of shape factors that best described the seeds of coniferous trees. Based on Fig. 1 and the results of seed examinations, shape factors should account for:

a) considerable differences between the shape of silver fir seeds and seeds of the remaining tree species,

b) considerable differences between the shape of English yew seeds and seeds of the remaining tree species,

c) minor similarities in the shape of European larch and Douglas-fir seeds,

d) minor similarities in the shape of Scots pine and Norway spruce seeds.

The results of an analysis of variance indicate that the above requirements were not fully met by any of the examined shape factors. Although they satisfied the first two conditions, the shape factors proposed by Grochowicz (K_m and K_w) seemed to be least suited for describing the shape of seeds from coniferous trees. Grochowicz's shape factors should be primarily used to describe seeds that are polyhedral (FRĄCZEK, WRÓBEL 2006), such as silver fir seeds. In remaining seeds, in particular English yew and European black pine seeds, the axis of rotation and seed length overlap, therefore they could be described with the application of Donev's shape factors (DONEV et al. 2004, FRĄCZEK, WRÓBEL 2006). The above conditions were also partially met by Mohsenin's and Wróbel's shape factors which could be used interchangeably to describe the shape of seeds from coniferous tree species native to Poland.

The results of a correlation analysis of the discussed shape factors are presented in Table 3. The values of Pearson's correlation coefficients are determined by seed species, which implies that the values of different shape factors are not mutually convertible. The most significant correlation was observed between shape factors K_w and α. Relatively significant correlations were noted between Mohsenin's shape factor (S_n) and the factors proposed by Grochowicz (K_m and K_w), Donev (α) and Wróbel (α_w), as well as between the shape factors described by Grochowicz (K_m) and Wróbel (α_w). No significant correlations (except for Norway spruce and silver fir seeds) were found between Donev's shape factor β and the shape factors proposed by Mohsenin (S_n) and Wróbel (α_w).

Table 3

Pearson's coefficients of correlation between seed shape factors

Correlation	Seed species						
	Scots pine[1]	European black pine[2]	Norway spruce[3]	European larch[4]	Silver fir[5]	Douglas-fir[6]	English yew[7]
$K_m \leftrightarrow K_w$	0.743	0.444	0.585	0.496	0.343	0.408	0.698
$K_m \leftrightarrow S_n$	0.925	0.850	0.921	0.847	0.865	0.805	0.928
$K_m \leftrightarrow \alpha$	-0.724	-0.451	-0.588	-0.457	-0.257	-0.389	-0.702
$K_m \leftrightarrow \beta$	0.202	0.523	0.703	0.410	0.675	0.456	0.492
$K_m \leftrightarrow \alpha_w$	0.943	-0.894	-0.940	-0.916	-0.915	-0.896	-0.935
$K_w \leftrightarrow S_n$	0.941	0.848	0.853	0.881	0.763	0.868	0.914
$K_w \leftrightarrow \alpha$	-0.981	-0.986	-0.994	-0.986	-0.953	-0.986	-0.994
$K_w \leftrightarrow \beta$	-0.498	-0.520	-0.160	-0.580	-0.447	-0.616	-0.278
$K_w \leftrightarrow \alpha_w$	-0.874	-0.767	-0.799	-0.771	-0.577	0.741	-0.892
$S_n \leftrightarrow \alpha$	-0.927	-0.849	-0.854	-0.856	-0.695	-0.854	-0.915
$S_n \leftrightarrow \beta$	-0.182	0.001	0.376	-0.133	0.221	-0.155	0.135
$S_n \leftrightarrow \alpha_w$	-0.977	-0.982	-0.990	-0.974	-0.949	-0.970	-0.995
$\alpha \leftrightarrow \beta$	0.507	0.516	0.155	0.615	0.511	0.634	0.267
$\alpha \leftrightarrow \alpha_w$	0.889	0.782	0.806	0.754	0.556	0.737	0.903
$\beta \leftrightarrow \alpha_w$	0.057	-0.126	-0.454	-0.051	-0.422	-0.051	-0.173

Critical values of correlation coefficients: [1] – 0.191; [2] – 0.177; [3] – 0.185; [4] – 0.188; [5] – 0.178; [6] – 0.179; [7] – 0.176

The average value of the coefficient of seed volume k, determined based on pycnometer measurements, ranged from 0.335 (silver fir seeds) to 0.522 (Norway spruce seeds) (Tab. 4). The sphere ($M1$), cylinder ($M2$), cuboid ($M5$), double cone ($M7$) and double triangular pyramid ($M9$) did not adequately model the equivalent diameter of coniferous tree seeds because their volume coefficients differed significantly from those measured with a pycnometer. The performed measurements produced the smallest relative error for Norway spruce seeds on the assumption that they had an ellipsoid shape (0.4%). The above model quite accurately described the seeds of the Scots pine (relative error of 7.6%), European black pine (10.1%) and English yew (3.4%). The volume of the above seeds was most accurately modeled by a right triangular prism ($M6$) which produced relative errors of 2.7%, 5.0% and 1.4%, respectively. The above model can also be used to describe the volume of European larch seeds, although the relative error was quite high at 19.0%. The volume coefficient of silver fir and Douglas-fir seeds was similar to that produced by a double quadrangular pyramid ($M8$) where the relative error was determined at 0.6% and 11.4%, respectively. The proposed models can be used for the purpose of designing seed transport, separation, drying and storage processes.

Table 4

Coefficients of seed volume and geometric shape models

Seed species	Volume coefficient									
	k	k_{M1}	k_{M2}	k_{M3}	k_{M4}	k_{M5}	k_{M6}	k_{M7}	k_{M8}	k_{M9}
Scots pine	0.487	0.693	0.847	0.564	0.524	1	0.5	0.282	0.333	0.167
European black pine	0.476	0.676	0.810	0.540				0.270		
Norway spruce	0.522	0.682	0.817	0.545				0.272		
European larch	0.420	0.727	0.874	0.583				0.291		
Silver fir	0.335	0.767	0.851	0.567				0.284		
Douglas-fir	0.376	0.811	0.873	0.582				0.291		
English yew	0.507	0.561	0.790	0.527				0.263		

Conclusions

1. The shape of coniferous tree seeds native to Poland can be described using one of the three groups of shape factors proposed by Mohsenin, Donev and Wróbel. The values of shape factors can be converted between groups only if the three principal seed dimensions, namely length, width and thickness, are known.

2. The shape and volume of coniferous tree seeds can be modeled with an ellipsoid for Scots pine, European black pine, Norway spruce and English yew

seeds, and a double right quadrangular pyramid for silver fir and Douglas-fir seeds. The volume of European larch seeds can be modeled with a right triangular prism.

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