Correlations between the Germination Capacity and Selected Physical Properties of Scots Pine (*Pinus sylvestris* L.) Seeds

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Abstract

The critical transport velocity, dimensions (thickness, width, length), the angle of sliding friction and weight of Scots pine seeds from three batches were determined. Seed color was assessed in using an organoleptic test, and seeds were divided into three groups: gray, black and other. The measured parameters were used to calculate the arithmetic and geometric mean diameter, aspect ratio, sphericity index, specific weight and density of seeds. The germination capacity was estimated every 12 hours, and the germination rate was determined for each seed. The analyzed attributes were compared by the Student's *t*-test for independent samples, single classification analysis of variance and a correlation analysis. The germination capacity was somewhat improved by eliminating seeds with the lowest thickness from the examined material. The separation of seeds into color groups in an optical grader and individual processing of each group proved to be economically unfeasible. The above approaches did not lead to a significant improvement in germination capacity or germination uniformity. The percentage of non-germinated seeds was nearly twice higher in the "other" group than in the remaining color groups.

Keys words: Scots pine seeds, physical properties, germination

Symbols:

C_g – germination capacity, %, D_a – arithmetic mean diameter, mm, D_g – geometric mean diameter, mm, m – seed weight, mg, m_D – specific seed weight, g·m^{-1}, R – aspect ratio, %, S_n – seed loss, %, S – standard deviation of trait, T, W, L – seed thickness, width and length, mm, T_g – time required to produce a healthy germ, day, T_o – time of germination test, day, W_g – germination rate, v – critical transport velocity of seeds, m·s^{-1}, V_g – germination viability, %, V_s – coefficient of trait variability, %, x, x_{max}, x_{min} – average, maximum and minimum value of trait, γ – angle of sliding friction, °, ρ – seed density, g·cm^{-3}, Φ – sphericity index, %.

Introduction

The Scots pine is a native to Europe and Asia where it occupies vast territories. Its range stretches from the Russian Far East to Denmark, the Elbe River and northern Bavaria. In the west of its range, the Scots pine occurs in the Scottish mountains, and in the south-west, it is found in the Pyrenees and the Balkan Peninsula (Wright et al. 1966, Puchniarski 2008, Turna and Güney 2009, Brus et al. 2011, Jaworski 2011). In the Baltic countries, there are optimal conditions for growth of Scots pine. This continental species tolerates considerable temperature fluctuations. It grows most on dry soils but occurs also in waterlogged areas and peatlands. The species thrives on deep soils, sand, loamy sand and light loam (Puchniarski 2008, Jaworski 2011).

In dense forests, pine seeds can be harvested from 30-40-year-old trees, and trees growing in open space begin to produce seeds already at the age of 10 years (Puchniarski 2008, Jaworski 2011). The species produces an abundant seed yield every 3÷5 years (Załęski 1995), and cones can be sampled from at least 10-20% of trees in every stand each year (Bodył and Załęski 2005).

Tree nurseries use seeds with the highest germination capacity (Janson and Załęski 1998). According to many authors (Kluczyński 1992, Załęski 1995, Castro 1999, Skrzypczyńska and Skrzyszewski 2000, Skrzypczyńska and Kozioł 2001, Buraczyk 2002, Moles and Westoby 2003, Sułkowska and Załęski 2003, Bodył et al. 2007, Sivaciošlu and Ayan 2008, Sevik et al. 2010, Sivaciošlu 2010), the yield potential and seed quality are affected by different factors including geographical location, weather conditions during cone and seed formation, genetic traits and age of the tree stand, tree size, type of habitat and soil, prevalence of diseases affecting cones and seeds, insect invasions and location of cones in the tree crown. Inadequate harvesting, storage and pre-sowing treatments can lead to the spoilage of even top-quality seed material (Janson and Załęski 1995, Załęski 1995, Aniśko et al. 2006, Bodył et al. 2007, Tylek 2010). Scots pine seeds with a moisture content of 7-9% are best suited for short-term storage. For long-term storage, the moisture content of Scots pine seeds should be reduced accordingly by drying (Załęski 1995). Subject to the location and year of harvesting, the critical moisture content of Polish Scots pine seeds ranges from 1 to 3% (Aniśko et al. 2006). Seed quality can be enhanced by separating filled seeds from empty seeds. Since empty seeds are considerably lighter, satisfactory results can be achieved with the use of pneumatic separators (Sarnowska and Więsik 1998, Tylek 1999, 2000). Scots pine seeds do not require pre-sowing treatment, but they can be stratified to encourage germination (Barzdajn 1991, Janson and Załęski 1998).

There is a general scarcity of published data about the correlations between the physical properties of tree seeds and their germination capacity. The majority of relevant research focuses on seed weight and its influence on the development of sprouts and seedlings (Mikola 1980, Castro 1999, Shankar 2006, Upadhaya et al. 2007, Wu and Du 2007, Norden et al. 2009, Buraczyk 2010). Subject to the analyzed seed species, the observed correlations were directly or inversely proportional. The effect of selected physical attributes of European larch (Kaliniewicz 2012a) and European spruce (Kaliniewicz 2012b) seeds on their germination capacity has been explored in the authors' previous work, and in this study, the above correlation is examined in Scots pine seeds.

Scots pine seeds comprise differently colored seeds, including in material harvested from the same tree (Załęski 1995, Aniszewska 2006), which has prompted the authors to investigate potential differences in the germination capacity of variously colored seeds. The discussed correlation could have significant implications for the design of seed cleaning and sorting processes. At present, the parameters of seed processing equipment are selected intuitively based on the results of cleaning trials, and seeds are sorted into categories that reflect their plumpness (Sarnowska and Więsik 1998).

The objective of this study was to determine the correlations between the basic physical attributes of Scots pine seeds (critical transport velocity, dimensions, angle of sliding friction, weight, arithmetic and geometric mean diameter, aspect ratio, sphericity index, specific weight, density and colour) and their germination capacity to eliminate low-quality seeds and to improve germination uniformity.

Materials and Methods

The experimental material comprised three batches of Scots pine seeds supplied by the seed extraction plant in Ruciane-Nida (Poland). Seeds were harvested from cones collected in seed regions No. 206 and 456 in Mazury-Podlasie and Mazowsze-Podlasie natural forest regions. The analyzed seed batches were harvested from the following tree stands:

a) registration No. MP/1/24287/05, category of seed propagation material: from an identified source, type: tree stand, municipality: Ruciane-Nida (21.35°E, 53.40°N), region of origin: 206, forest habitat: fresh mixed broadleaved forest, age: unknown, year of cone harvest: 2011 (symbol: ZZ-11),

b) registration No. MP/1/24189/05, category of seed propagation material: from an identified source (deleted), type: tree stand, municipality: Mikołajki (21.32°E, 53.47°N), region of origin: 206, forest habitat: fresh mixed broadleaved forest, age: unknown, year of cone harvest: 2007 (symbol: ZZ-07),

c) registration No. MP/3/41012/05, category of seed propagation material: qualified, type: seed plantation, municipality: Łomża (22.04°E, 53.07°N), region of origin: 456, forest habitat: fresh mixed broadleaved forest, age: 12 years, year of cone harvest: 2010 (symbol: KW-10).

Seed batches were divided by halving (Załęski 1995) to produce research samples of around 100 seeds each. The selected method produced samples of the following size: ZZ-11 – 120 seeds, ZZ-07 – 117 seeds, KW-10 – 121 seeds.

Critical transport velocity was determined in the Petkus K-293 pneumatic classifier, seed dimensions were determined by using the MWM 2325 workshop microscope (length and width) and a thickness gauge, the angle of sliding friction was measured on a horizontal plane with an adjustable angle of inclination, and seed weight was determined on the WAA 100/C/2 laboratory scale. All measurements were performed according to the methods previously described by Kaliniewicz et al. (2011, 2012a, 2012b).

Seeds were divided into colour groups by visual examination. Seeds, which were uniformly coloured on minimum 75% of their surface area, were classified as gray or black. Samples that did not meet the above requirements, including spotted and brown seeds, were classified as the "other colour" group.

The measured parameters were used to determine the following seed indicators:

a) arithmetic D_a and geometric mean diameter D_g, aspect ratio R and sphericity index Φ (Mohsenin 1986):

$$D_a = \frac{T + W + L}{3} \quad (1)$$

$$D_g = (T \cdot W \cdot L)^{1/3} \quad (2)$$

$$R = \frac{W}{L} \times 100 \quad (3)$$

$$\Phi = \frac{(T \cdot W \cdot L)^{1/3}}{L} \times 100 \quad (4)$$

b) specific weight (Kaliniewicz 2013):

$$m_D = \frac{m}{D_g} \quad (5)$$

c) seed density ρ – was determined from seed volume which was calculated experimentally by Kaliniewicz et al. (2012c) with the use of a pycnometer:

$$\rho = \frac{m}{0.487 \cdot T \cdot W \cdot L} \quad (6)$$

In the germination test, seeds were placed on moistened filter paper in a glass tank covered with a glass lid. The experiment was carried out at the recommended temperature range (20 to 30°C) under exposure to natural light. Evaporated water was supplemented daily with a sprinkler, and filter paper was kept moist throughout the experiment. Seed germination progress was evaluated twice daily between 8 a.m. and 9 a.m. and between 8 p.m. and 9 p.m. Seeds that produced a sprout with a minimum length of 75% seed length were classified as germinated (Załęski 1995). Observations were continued for 21 days. The germination rate index W_g was determined with the use of the below equation:

$$W_g = \frac{T_o - T_n}{T_o} \quad (7)$$

Germination time was the time of observation plus one day. In this experiment, germination time was 22 days.

Germination energy V_g and germination capacity C_g were determined based on the ratio of the number of seeds that had sprouted in 7 and 21 days to the number of seeds in the analyzed sample.

The results were processed with the use of Statistica PL v. 10 application. Statistical calculations were performed at significance level of α=0.05. The results of parameter differentiation in every seed batch were evaluated by ANOVA by decomposing the overall differentiation effect and expressing the quotient of mean values in line with Fisher-Snedecor distribution. The normality of each group was verified with the Shapiro-Wilk test, and equality of variances was checked with Levene's test. Where the null hypothesis of equal population means was rejected, i.e. when:

$$F = \frac{MS_{Treatment}}{MS_{Error}} \geq F_\alpha \quad (8)$$

multiple comparisons were performed post-hoc to narrow down the differences and identify homogenous groups with the use of Duncan's test. The differences in physical parameters and indicators calculated for germinated and non-germinated seeds were determined with the use of Student's t-test for independent samples. A correlation analysis was performed to determine the strength and direction of correlations between the analyzed parameters of Scots pine seeds. The degrees of correlation were evaluated with the use of Pearson's correlation coefficients (Luszniewicz and Słaby 2008, Rabiej 2012).

Results

The parameters of the analyzed seeds are presented in Table 1. The physical attributes of Scots pine seeds from the three examined batches changed in the following range of values: critical transport velocity – of around 5.8 to around 8.5 $m \cdot s^{-1}$, thickness – of 1.04 to 1.89 mm, width – of 1.84 to 3.46 mm, length – of 3.10 to 5.55 mm, angle of sliding friction – of 24 to 56° and weight – of 3.1 to 11.7 mg. The indicators calculated based on the above attributes took on the following values: arithmetic mean diameter – of 2.18 to 3.45 mm, geometric mean diameter – of 2.00 to 3.15 mm, aspect ratio – of around 47 to around 76%, sphericity index – of around 50 to around 71%, specific seed weight – of 1.67 to 3.78 $g \cdot m^{-1}$ and density – of around 0.6 to around 1.1 $g \cdot cm^{-3}$. In the group of analyzed attributes,

Table 1. Statistical distribution of the physical properties of Scots pine seeds

Batch of seeds	Property / indicator	x_{min}	x_{max}	x	S	V_s
ZZ-11	v	5.78	7.98	6.93b	0.442	6.38
	T	1.04	1.60	1.39c	0.109	7.87
	W	2.01	2.97	2.43b	0.184	7.58
	L	3.17	4.84	4.09b	0.319	7.80
	γ	24	49	34.2b	4.938	14.45
	m	3.6	8.0	5.54b	0.894	16.15
	D_a	2.23	2.93	2.63b	0.155	5.87
	D_g	2.02	2.72	2.39b	0.134	5.59
	R	46.57	69.40	59.67a	5.034	8.44
	Φ	52.75	66.93	58.71b	3.075	5.24
	m_D	1.67	3.18	2.30b	0.266	11.58
	ρ	0.664	1.041	0.833b	0.066	7.93
	W_g	0	0.841	0.673a	0.216	32.03
ZZ-07	v	5.78	8.53	7.14a	0.553	7.74
	T	1.14	1.73	1.45b	0.129	8.88
	W	1.84	2.83	2.41b	0.200	8.30
	L	3.10	4.87	4.06b	0.366	9.01
	γ	26	56	35.4b	5.495	15.54
	m	3.1	8.5	5.60b	1.099	19.61
	D_a	2.18	3.02	2.64b	0.183	6.93
	D_g	2.00	2.77	2.41b	0.161	6.69
	R	48.14	70.44	59.55a	5.278	8.86
	Φ	50.70	68.23	59.73a	3.704	6.20
	m_D	1.55	3.11	2.30b	0.319	13.85
	ρ	0.623	0.979	0.816c	0.061	7.49
	W_g	0	0.864	0.642a	0.248	38.70
KW-10	v	5.23	8.53	7.22a	0.487	6.75
	T	1.16	1.89	1.50a	0.154	10.21
	W	2.15	3.46	2.68a	0.239	8.91
	L	3.42	5.55	4.47a	0.396	8.86
	γ	30	46	36.7a	3.746	10.21
	m	4.4	11.7	7.43a	1.599	21.52
	D_a	2.34	3.45	2.88a	0.211	7.34
	D_g	2.17	3.15	2.62a	0.195	7.44
	R	48.65	75.94	60.22a	5.559	9.23
	Φ	49.69	70.53	58.76b	3.808	6.48
	m_D	2.00	3.78	2.81a	0.406	14.45
	ρ	0.734	1.065	0.849a	0.056	6.58
	W_g	0	0.818	0.686a	0.147	21.50

a, b, c – different letters denote significant differences

the highest coefficient of variation was reported for seed weight, and in the group of calculated indicators – for specific weight. The germination rate of Scots pine seeds ranged from 0 to 0.864, and it was characterized by the highest coefficient of variation in the group of analyzed attributes and indicators.

The results of an analysis of variance for a single classification component indicate that seeds from the three examined batches differed in thickness and density. No significant differences were noted between the coefficients of proportionality or germination rates of seeds from the evaluated batches. Significant differences in the remaining seed properties and indicators were determined only between seeds from the same batches.

Germination capacity C_g of seeds from batches ZZ-11, ZZ-07 and KW-10 was determined at 93.3%, 89.7% and 96.7%, respectively, and their germination energy V_g – at 76.7%, 74.4% and 71.1%, respectively. For the sake of simplicity, seeds from the analyzed batches were incorporated into a single experimental group with germination capacity C_g=93.3% and germination energy V_g=74.0%. The above seeds fulfilled the requirements of Polish quality class II (PN-R-65700:1998).

The results of the Student's t-test for independent samples revealed that in most cases, germinated seeds were characterized by higher average values of physical parameters (excluding density) and the calculated indicators than non-germinated seeds, but significant differences were observed only with regard to seed thickness (Table 2).

Table 2. Significance of differences in the physical properties and calculated indicators of germinated and non-germinated Scots pine seeds

Property / indicator	Seeds	
	germinated	non-germinated
v	7.11a	6.92a
T	1.45a	1.39b
W	2.51a	2.43a
L	4.21a	4.13a
γ	35.5a	34.0a
m	6.23a	5.70a
D_a	2.72a	2.65a
D_g	2.48a	2.40a
R	59.87a	59.00a
Φ	59.11a	58.36a
m_D	2.48a	2.34a
ρ	0.832a	0.839a

a, b – different letters denote significant differences

The examined material comprised 21% gray seeds, 40% black seeds and 39% seeds from the "other" colour group (Figure 1). The physical properties and the calculated indicators of seeds from different colour groups are compared in Table 3. Gray, black and dif-

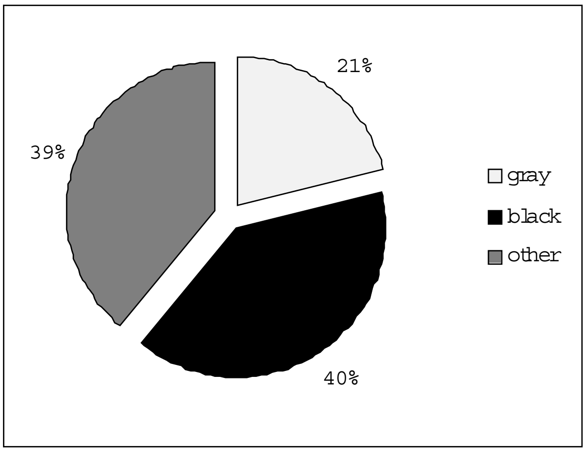

Figure 1. Percentage shares of different-coloured Scots pine seeds

Table 3. Significance of differences in the physical properties and calculated indicators of seeds from different colour groups

Property / indicator	Seed color		
	gray	black	other
v	7.13a	7.13a	7.05a
T	1.44ab	1.47a	1.43b
W	2.51ab	2.55a	2.46b
L	4.30a	4.22ab	4.14b
γ	35.1a	35.5a	35.5a
m	6.38a	6.40a	5.88b
D_a	2.75a	2.75a	2.67b
D_g	2.49a	2.51a	2.43b
R	58.70b	60.57a	59.64ab
Φ	58.22b	59.53a	59.05ab
m_D	2.53a	2.53a	2.39b
ρ	0.836a	0.830a	0.833a
W_g	0.707a	0.676ab	0.636b

a, b – different letters denote significant differences

ferently coloured seeds did not differ with regard to their critical transport velocity, the angle of sliding friction or density. Gray and black seeds were most likely to form homogenous groups based on the values of a given attribute or indicator. No significant differences in germination rate were noted between the above groups, although gray seeds germinated somewhat earlier than black seeds. Significant differences in germination rate were noted between gray seeds and "other" seeds.

The results of the analysis of variance and Student's t-test for independent samples of germinated and non-germinated Scots pine seeds from differently coloured groups are presented in Figures 2 and 3. In most cases (excluding the critical transport velocity of black seeds), no significant differences were observed between viable and non-viable seeds. Black and "other" non-germinated seeds were generally characterized by lower average values, and gray seeds – by higher average values of the analyzed parameters and indicators. A comparison of the respective groups of differently colored, germinated seeds revealed similar correlations to those noted in the previous analysis. In the group of non-germinated seeds, significant variations were reported in the length of gray and remaining (black and "other") seeds and in the arithmetic mean diameter of gray and "other" seeds.

The results of a linear correlation analysis (Table 4) suggest that the germination rate index is not significantly correlated with the investigated parameters. The separation of seed material into differently coloured groups had no effect on the above. An absence of strong correlations between the analyzed traits and the germination rate index was also demonstrated by the variability of the studied relations. The value of the germination rate index was directly proportional to the analyzed parameters in selected seed colour groups, whereas an inversely proportional relationship was observed in other colour groups. Significant correlations were reported in the batch of seeds from the

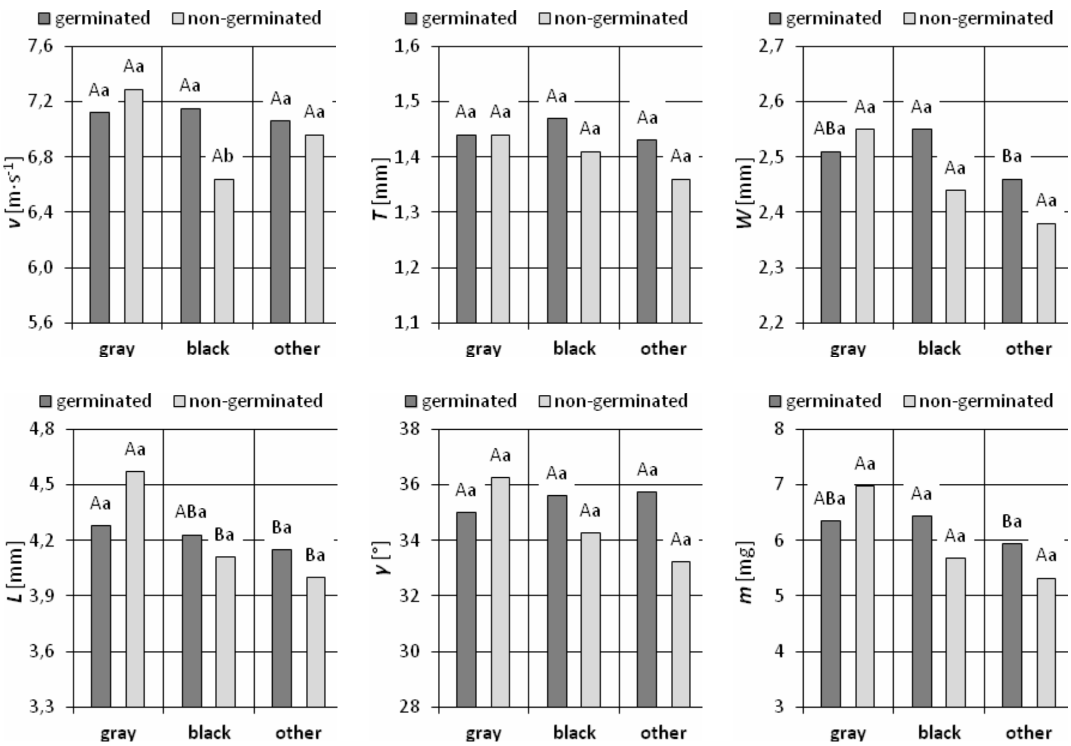

Figure 2. Significance of differences between the physical properties of Scots pine seeds: A, B – different letters denote significant differences between seeds of a given colour; a, b – different letters denote significant differences between germinated and non-germinated seeds

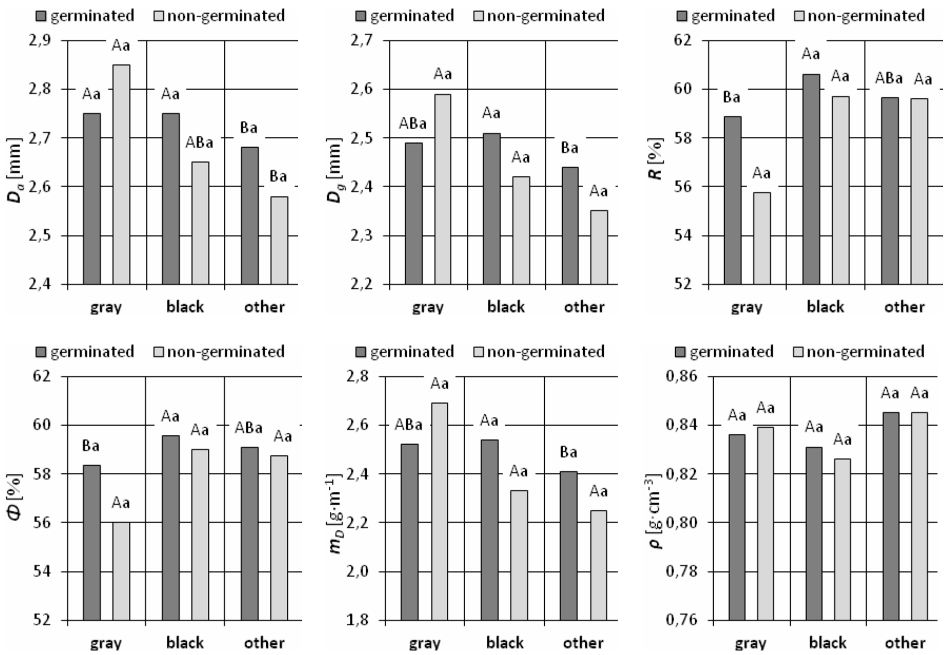

Figure 3. Significance of differences between the indicators of Scots pine seeds: A, B – different letters denote significant differences between seeds of a given colour; a, b – different letters denote significant differences between germinated and non-germinated seeds

Table 4. Coefficients of Pearson's linear correlation between the rate of germination and the physical parameters of Scots pine seeds

Variables		Correlation coefficients calculated for seeds:			
X	*Y*	gray	black	other	overall
W_g	*v*	-0,024	0,087	0,017	0,114*
	T	0,146	-0,015	0,215*	0,105
	W	0,146	-0,054	0,162	0,079
	L	0,150	-0,065	0,096	0,057
	γ	-0,119	-0,014	-0,195*	-0,116*
	m	0,146	-0,063	0,137	0,066
	D_a	0,176	-0,064	0,163	0,087
	D_g	0,181	-0,051	0,197*	0,103
	R	0,004	0,006	0,057	0,018
	Φ	-0,016	0,031	0,088	0,035
	m_D	0,127	-0,059	0,123	0,060
	ρ	-0,126	-0,007	-0,128	-0,077

* – correlation coefficients higher than the critical value

"other" colour group, but instances of practical significance, when the coefficient of correlation is at least 0.4, were not observed. In all seed batches, the germination rate index was correlated with seed critical transport velocity and the angle of sliding friction. However, correlation coefficients were generally low and had no practical significance.

Histograms showing the distribution of the germination rate index for groups of differently coloured seeds, analyzed individually and jointly, are presented in Figure 4. Those distributions are highly similar, which indicates that the separation of seeds into differently coloured groups does not considerably improve germination rate or germination uniformity through time. The percentage of non-germinated seeds was nearly twice higher in the "other" colour group than in gray and black seed groups.

Discussion

The highest values of the coefficient of variation of physical attributes were noted for seed weight (from 16.15 to 21.52%). For the remaining parameters, the coefficient of variation was determined in the range of 6.4 to 15.5%, which is consistent with the results obtained by other authors (Czernik 1983a, Tylek 1998, Bodył and Załęski 2005, Sivaciošlu 2010). The range of changes in the evaluated physical attributes and their average values are similar to those reported for Polish seeds in previous studies (Czernik 1983a, 1983b, Wesoły et al. 1984, Załęski 1995, Tylek 1998, Bodył and Załęski 2005, Bodył et al. 2007, Buraczyk 2010, Kaliniewicz et al. 2011). The analyzed seeds were somewhat lighter than the material originating from southern Europe (Castro 1999, Sivaciošlu and Ayan 2008, Carrillo-Gavilįn et al. 2010, Sevik et al. 2010, Sivaciošlu 2010), but they were heavier than the seeds from northern regions of the continent (Karlsson and Örlander 2002, Mikola 1980). According to Oleksyn et al. (2001), the weight of Scots pine seeds is largely determined by the local climate, and seeds originating from severe climates are generally lighter. A similar correlation between seed weight and the geographic location of trees was reported for other tree species by Moles and Westoby (2003).

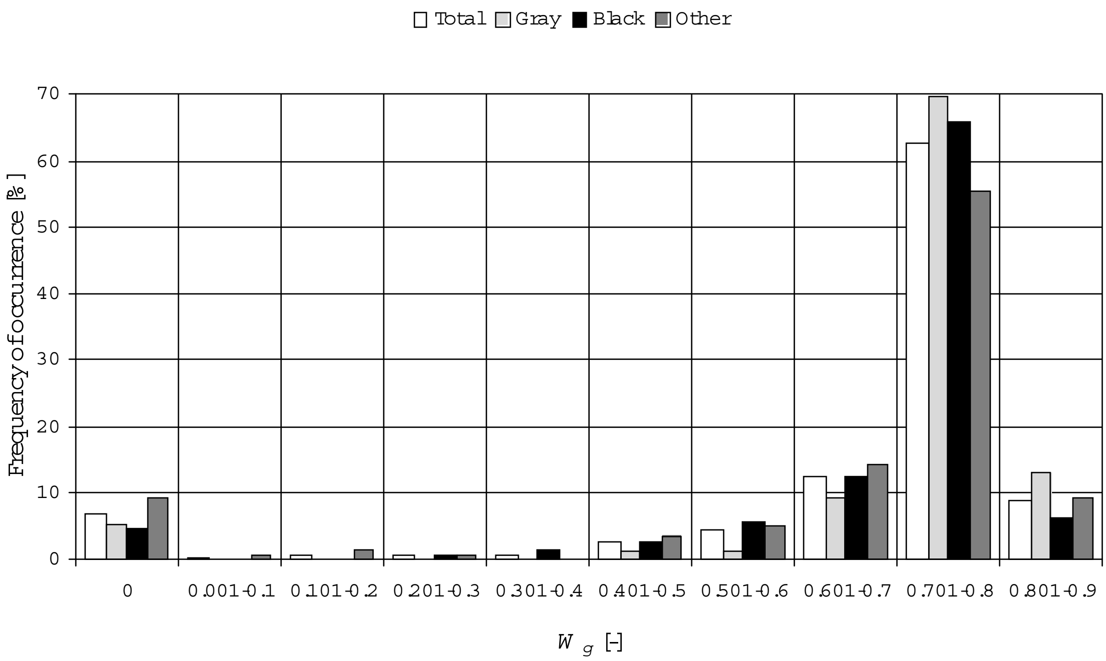

Figure 4. Germination rate of Scots pine seeds sorted based on colour

Based on the mean values of the coefficient of proportionality, Scots pine seeds appear to be most similar to African star apple (Oyelade et al. 2005) and acorn seeds (Fos'hat et al. 2011), whereas the mean values of the sphericity index show the greatest resemblance to wheat (Kalkan and Kara 2011, Markowski et al. 2013), African breadfruit (Omobuwajo et al. 1999) and *Jatropha curcas* kernels (Karaj and Müller 2010). The germination rate index W_g was characterized by significant variation in the range of 27 to 44%. Scots pine seeds were characterized by lower variation in germination rates than European spruce (Kaliniewicz et al. 2012b) and European larch seeds (Kaliniewicz et al. 2012a). This implies that a large number of Scots pine seeds germinate nearly at the same time, and the distribution of days on which sprouts appear is more clustered in comparison with European spruce and European larch seeds.

The differences in the thickness of germinated and non-germinated Scots pine seeds suggest that seed separation in screens with longitudinal mesh openings and the use of selected seed fractions for sowing can somewhat improve germination. When the seed thickness interval is set at T=1.2 mm, approximately 21% of non-germinated seeds will be discarded together with the fine seed fraction. Approximately 2.4% of healthy sprouting seeds will be discarded, and the resulting loss will account for around 3.6% of all seeds. The proposed separation process will improve the quality of seed material whose germination capacity will reach C_g=94.5% and germination energy V_g=75.9%.

In the examined material, the percentage share of black seeds and seeds from the "other" color group was nearly identical, whereas the percentage of white seeds was twice lower. The percentage share of black seeds noted in this study is similar to that reported by Aniszewska (2006), and the percentage of gray seeds is lower than that found in material harvested in Turkey (28 to 42%) (Sevik et al. 2010). The relevant literature provides ambiguous and inconclusive results regarding the correlations between the colour and germination rate of seeds. Oliveira et al. (2013) analyzed parsley seeds and Ertekin and Kirdar (2010) investigated honey locust seeds to observe that lighter seeds germinate earlier, whereas a reverse trend was observed by Atak et al. (2008) in pea seeds. In our study, light (gray) Scots pine seeds where characterized by the highest germination rate, which implies that they sprouted faster than the remaining seeds (black and other) in the first days of the germination test.

According to published data, seed weight affects germination and seedling development in the first year. The above applies to the seeds of the Scots pine (Castro 1999, Buraczyk 2010), white pine (Parker et al. 2007), European spruce (Mikola 1980), silver fir (Sabor 1984), jackfruit (Khan 2004), *Prunus yenkinsii* (Upadhaya et al. 2007) and oaks (Bonfil 1998, Seiwa 2000, Khan and Shankar 2001, Quero et al. 2007). Those correlations were not observed by Szczygieł (1981) or in this study. The absence of a significant correlation between the weight and germination rate of seeds can be regarded as a positive phenomenon, because it implies that seeds will have equal opportunities to germinate in the natural environment, although large seeds may be more often consumed by pests and animals (Moles et al. 2003).

Conclusions

1. Germinated and non-germinated Scots pine seeds differed significantly only with regard to their thickness, which suggests that seed quality can be improved by separating the smallest seeds in a sieve with longitudinal mesh openings. This process leads to the loss of germinated seeds, and it produces only a minor improvement in germination capacity and germination energy, therefore, it should be applied only when other seed processing methods are not available and when seed parameters reach the highest possible values in a given quality class.

2. No significant differences in critical transport velocity, the angle of sliding friction or density were observed between gray, black and "other" Scots pine seeds. In comparison with non-germinated seeds, black and "other" germinated seeds were characterized by higher average values of physical parameters, including critical transport velocity, thickness, width, length, the angle of sliding friction and weight, whereas gray germinated seeds were characterized by lower average values of the above parameters, but significant differences were observed only with respect to the critical transport velocity of black seeds. Non-significant variations in the parameters of germinated and non-germinated seeds from different colour groups indicate that seed quality cannot be considerably improved by separating seeds in an optical grader (based on seed colour) or performing the separation process independently for every seed fraction.

3. The physical attributes and the calculated indicators of Scots pine seeds have no significant effect on the germination rate index. None of the analyzed traits can be regarded as a distinctive attribute based on which seeds can be separated to improve their germination uniformity (germination in the same period of time). The separation of differently coloured seed groups and independent processing of each group does not improve germination uniformity either.

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References

Aniszewska, M. 2006. Connection between shape of pine (*Pinus sylvestris*) cones and weight, colour and number of seeds extracted from them. Electronic Journal of Polish Agricultural Universities, Forestry, Volume 9, Issue 1. Available Online http://www.ejpau.media.pl/volume9/issue1/art-03.html.

Aniśko, E., Witowska, O. and Załęski, A. 2006. Wpływ warunków suszenia nasion brzozy brodawkowatej, olszy czarnej, sosny zwyczajnej i świerka pospolitego na ich żywotność [Effect of dryings conditions on viability of common birch, black alder, Scots pine and Norway spruce seeds]. *Leśne Prace Badawcze* 2: 91-13 (in Polish with English abstract).

Atak, M., Kaya, M.D., Kaya, G., Kaya, M. and Khawar, K.M. 2008. Dark green colored seeds increase the seed vigor and germination ability in dry green pea (*Pisum sativum* L.). *Pakistan Journal of Botany* 40(6): 2345-2354.

Barzdajn, W. 1991. Wpływ niektórych zabiegów przedsiewnych na kiełkowanie nasion sosny zwyczajnej (*Pinus silvestris* L.) [Influence of Some Treatments Preceding the Sowing on Germination of Seeds of Scots Pine (*Pinus silvestris* L.)]. *Sylwan* 10: 19-25 (in Polish with English abstract).

Bodył, M., Witowska, O. and Załęski, A. 2007. Przyczyny obniżonej żywotności niektórych partii nasion sosny zwyczajnej (*Pinus sylvestris* L.), pozyskanych w Polsce zimą 2005/2006 [Reasons for reduced viability of some Scots pine (*Pinus sylvestris* L.) seeds lots harvested in Poland in the winter season 2005/2006]. *Leśne Prace Badawcze* 4: 47-65 (in Polish with English abstract).

Bodył, M. and Załęski, A. 2005. Intensywność obradzania i jakość nasion sosny zwyczajnej (*Pinus sylvestris* L.) na stałych powierzchniach obserwacyjnych monitoringu lasu w latach 1996–2003 [Intensity of seeding and quality of scots pine (*Pinus sylvestris* L.) seeds on permanent observation plots subjected to forest monitoring between 1996 and 2003]. *Leśne Prace Badawcze* 2: 57-72 (in Polish with English abstract).

Bonfil, C. 1998. The effects of seed size, cotyledon reserves, and herbivory on seedling survival and growth in *Quercus rugosa* and *Q. laurina* (Fagaceae). *American Journal of Botany* 85(1): 79-87.

Buraczyk, W. 2002. Wpływ grubości i wysokości świerków na ich owocowanie w Puszczy Białowieskiej [The effect of the width and height on fruit production of Norway spruce in the Białowieża Primeval Forest]. *Sylwan* 4: 25-33 (in Polish with English abstract).

Buraczyk, W. 2010. Właściwości nasion a cechy morfologiczne siewek sosny zwyczajnej (*Pinus sylvestris* L.) [Seed characteristics and morphological features of Scots pine (*Pinus sylvestris* L.) seedlings]. *Leśne Prace Badawcze* 71(1): 13-20 (in Polish with English abstract).

Carrillo-Gavilán, M.A., Lalagüe, H. and Vilà, M. 2010. Comparing seed removal of 16 pine species differing in invasiveness. *Biological Invasions* 12: 2233-2242.

Castro, J. 1999. Seed mass versus seedling performance in Scots pine: a maternally dependent trait. *New Phytologist* 144: 153-161.

Czernik, Z. 1983a. Badania właściwości geometrycznych nasion sosny zwyczajnej, świerka pospolitego i modrzewia europejskiego [Studies of geometrical features of seeds of Scotch pine, Norway spruce and European larch]. *Sylwan* 7: 31-40 (in Polish with English abstract).

Czernik, Z. 1983b. Badania właściwości aerodynamicznych nasion sosny zwyczajnej, świerka pospolitego i modrzewia europejskiego [Studies of aerodynamical features of seeds of Scotch pine, Norway spruce and European larch]. *Sylwan* 9/10: 31-40 (in Polish with English abstract).

Ertekin, M. and Kirdar, E. 2010. Effects of seed coat colour on seed characteristics of honeylocust (*Gleditsia triacanthos*). *African Journal of Agricultural Research* 5(17): 2434-2438.

Fos'hat, M., Etemad, V., Gharibzahedi, S.M.T. and Ghahderijani, M. 2011. Physical, mechanical and aerodynamic properties of Acorn (*Quercus suber* L.) as potentials for development of processing machines. *Australian Journal of Crop Science* 5(4): 473-478.

Janson, L. and Załęski, A. 1998. Wykorzystanie biologicznych właściwości nasion w produkcji szkółkarskiej [The use of biological properties of seed in nursery production]. *Sylwan* 2: 59-70 (in Polish with English abstract).

Jaworski, A. 2011. Hodowla lasu. Tom III. Charakterystyka hodowlana drzew i krzewów leśnych [Silviculture. Volume 3. Breeding characteristics of forest trees and shrubs]. Ed. PWRiL, Warszawa (in Polish).

Kaliniewicz, Z. 2013. Analysis of frictional properties of cereal seeds. *African Journal of Agriculture Research* (in press).

Kaliniewicz, Z., Grabowski, A., Liszewski, A. and Fura, S. 2011. Analysis of correlations between selected physical attributes of Scots pine seeds. *Technical Sciences* 14(1): 13-22.

Kaliniewicz, Z., Markowski, P., Anders, A., Rawa, T., Liszewski, A. and Fura, S. 2012a. Correlations between the germination capacity and selected attributes of European larch seeds (*Larix decidua* Mill.). *Technical Sciences* 15(2): 229-242.

Kaliniewicz, Z., Markowski, P., Rawa, T., Grabowski, A. and Fura, S. 2012b. Współzależność między zdolnością kiełkowania a wybranymi cechami nasion świerka pospolitego *(Picea abies)* [A correlation between germination capacity and selected physical characteristics of Norway spruce (*Picea abies*) seeds]. *Inżynieria Przetwórstwa Spożywczego* 1/4: 13-17 (in Polish with English abstract).

Kaliniewicz, Z., Tylek, P., Markowski, P., Anders, A., Rawa, T. and Zadrożny, M. 2012c. Determination of shape factors and volume coefficients of seeds from selected coniferous trees. *Technical Sciences* 15(2): 217-228.

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

Karaj, S. and Müller, J. 2010. Determination of physical, mechanical and chemical properties of seeds and kernels of *Jatropha curcas* L. *Industrial Crops and Product* 32: 129-138.

Karlsson, Ch. and Örlander, G. 2002. Mineral nutrients in needles of *Pinus sylvestris* seed trees after relase cutting and their correlations with cone production and seed weight. *Forest Ecology and Management* 166: 183-191.

Khan, M.L. 2004. Effects of seed mass on seedling success in *Artocarpus heterophyllus* L., a tropical tree species of north-east India. *Acta Oecologica* 25: 103-110.

Khan, M.L. and Shankar, U. 2001. Effect of seed weight, light regime and substratum microsite on germination and seedling growth of *Quercus semiserrata* Roxb. *Tropical Ecology* 42(1): 117-125.

Kluczyński, B. 1992. Plonowanie i jakość świerka pospolitego [*Picea abies* (L.) Karst] w zależności od strefy w koronie oraz wybranych biologicznych i siedliskowych cech drzew [Yielding and quality of Norway spruce [*Picea abies* (L.) Karst.] seeds in dependence on the part of crown and chosen biological and site-related characteristics of trees]. *Sylwan* 5: 25-35 (in Polish with English abstract).

Luszniewicz, A. and Słaby, T. 2008. Statystyka z pakietem komputerowym STATISTICA PL. Teoria i zastosowanie [STATISTICA PL software package. Theory and applications]. Ed. C.H. Beck, Warszawa (in Polish).

Markowski, M., Żuk-Gołaszewska, K. and Kwiatkowski, D. 2013. Influence of variety on selected physical and mechanical properties of wheat. *Industrial Crops and Product* 47: 113-117.

Mikola, J. 1980. The effect of seed size and duration of growth on the height of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) provenances and progenies at the nursery stage. *Silva Fennica* 14(1): 84-94.

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

Moles, A.T., Warton, D.I. and Westoby, M. 2003. Do small-seeded species have higher survival through seed predation than large-seeded species? *Ecology* 84(12): 3148-3161.

Moles, A.T. and Westoby, M. 2003. Latitude, seed predation and seed mass. *Journal of Biogeography* 30(1): 105-128.

Murat, E. 2002. Szczegółowa hodowla lasu [Silviculture]. Ed. Oficyna Edytorska „Wydawnictwo Świat", Warszawa (in Polish).

Norden, N., Daws, M.I., Antoine, C., Gonzalez, M.A., Garwood, N.C. and Chave, J. 2009. The relationship between seed mass and mean time to germination for 1037 tree species across five tropical forests. *Functional Ecology* 23(1): 203-210.

Oleksyn, J., Reich, P.B., Tjoelker, M.G. and Chalupka, W. 2001. Biogeographic differences in shoot elongation pattern among European Scots pine populations. *Forest Ecology and Management* 148: 207-220.

Oliveira, S.F., Costa, D.S., Mello, S.C., Novembre, A.D.L.C. and Gomes-Junior, F.G. 2013. Germination of parsley seeds influenced by mericarps color and internal morphology. *Horticultura Brasileira* 31: 231-235.

Omobuwajo, T.O., Akande, E.A. and Sanni, L.A. 1999. Selected physical, mechanical and aerodynamic properties of African breadfruit (*Treculia africana*) seeds. *Journal of Food Engineering* 40: 241-244.

Oyelade, O.J., Odugbenro, P.O., Abioye, A.O. and Raji, N.L. 2005. Some physical properties of African star apple (*Chrysophyllum alibidum*) seeds. *Journal of Food Engineering* 67: 435-440.

Palowski, B. 1998. Plonowanie sosny zwyczajnej (*Pinus sylvestris* L.) na obszarach zanieczyszczonych przez emisje przemysłowe [Yielding of Scots pine (*Pinus sylvestris* L.) on areas polluted with industrial emissions]. *Sylwan* 12: 103-109 (in Polish with English abstract).

Parker, W.C., Noland, T.L. and Morneault, A.E. 2007. The effects of seed mass on germination, seedling emergence, and early seedling growth of eastern white pine (*Pinus strobus* L.). *New Forests* 32: 33-49.

PN-R-65700:1998. Materiał siewny – Nasiona drzew i krzewów leśnych i zadrzewieniowych [Seeds of forest trees and shrubs]. Polish Committee for Standardization (in Polish).

Puchniarski, T.H. 2008. Sosna zwyczajna. Hodowla i ochrona [The Scots pine – breeding and conservation]. Ed. PWRiL, Warszawa (in Polish).

Quero, J.L., Villar, R., Marańón, T., Zamora, R. and Poorter L. 2007. Seed-mass effects in four Mediterranean *Quercus* species (Fagaceae) growing in contrasting light environments. *American Journal of Botany* 94(11): 1795-1803.

Rabiej, M. 2012. Statystyka z programem Statistica [Statisctics in Statistica software]. Ed. Helion, Gliwice (in Polish).

Sabor, J. 1984. Zależność między ciężarem a zdolnością kiełkowania nasion jodły pospolitej [Relation between the weight and the germination capacity of seed of silver fir]. *Sylwan* 4: 59-69 (n Polish with English abstract).

Sarnowska, G. and Więsik, J. 1998. Wyłuszczarnia w Czarnej Białostockiej. Część III. Czyszczenie i separacja nasion [Seed Extraction Plant in Czarna Białostocka. Part III. Seed cleaning and separation]. *Przegląd Techniki Rolniczej i Leśnej* 1: 19-21 (in Polish).

Seiwa, K. 2000. Effects of seed size and emergence time on tree seedling establishment: importance of developmental constraints. *Oecologia* 123: 208-215.

Sevik, H., Ayan, S., Turna, I. nad Yahyaoglu, Z. 2010. Genetic diversity among populations in Scotch pine (*Pinus silvestris* L.) seed stand of Western Black Sea Region in Turkey. *African Journal of Biotechnology* 9(43): 7266-7272.

Shankar, U. 2006. Seed size as a predictor of germination success and early seedling growth in 'hollong' (*Dipterocarpus macrocarpus* Vesque). *New Forests* 31: 305-320.

Sivaciošlu, A. 2010. Genetic variation in seed cone characteristics in a clonal seed orchard of Scots pine (*Pinus sylvestris* L.) grown in Kastamonu-Turkey. *Romanian Biotechnological Letters* 15(6): 5695-5701.

Sivaciošlu, A., Ayan, S. 2008. Evaluation of seed production of Scots pine (*Pinus sylvestris* L.) clonal seed orchard with cone analysis method. *African Journal of Biotechnology* 7(24): 4393-4399.

Skrzypczyńska, M. and Kozioł, M. 2001. Ocena jakościowa nasion modrzewia europejskiego *Larix Decidua* Mill. pochodzących z wybranych stanowisk południowej Polski [The qualitative estimation of European larch *Larix decidua* Mill. seeds originating from the selected localities in southern Poland]. *Sylwan* 5: 39-44 (in Polish with English abstract).

Skrzypczyńska, M. and Skrzyszewski, J. 2000. Ocena jakościowa nasion sosny zwyczajnej *Pinus sylvestris* L. pochodzących z wybranych stanowisk południowej Polski [The qualitative estimation of Scots pine seeds originated from the selected localities of southern Poland]. *Sylwan* 5: 85-90 (in Polish with English abstract).

Sułkowska, M. and Załęski, A. 2003. Zróżnicowanie genetyczne reakcji nasion rodów sosny zwyczajnej (*Pinus sylvestris* L.) na test przyśpieszonego postarzania [Genetic variation response of Scots pine (*Pinus sylvestris* L.) seeds of different progenies of the accelerated ageing test]. *Sylwan* 5: 42-46 (in Polish with English abstract).

Szczygieł, K. 1981. Wpływ ciężaru nasion świerka na wysokość siewek wyhodowanych w optymalnych warunkach [The effect of spruce seed weight upon the height of seedlings grown under optima conditions]. *Sylwan* 1: 33-39 (in Polish with English abstract).

Turna, I. and Güney, D. 2009. Altitudinal variation of some morphological characters of Scots pine (*Pinus sylvestris* L.) in Turkey. *African Journal of Biotechnology* 8(2): 202-208.

Tylek, P. 1998. Cechy planimetryczne nasion drzew liściastych [Planimetric features of deciduous tree seeds]. *Przegląd Techniki Rolniczej i Leśnej* 1:22-98 (in Polish).

Tylek, P. 1999. Problemy selekcji pneumatycznej nasion drzew leśnych [Problems of pneumatic selection of forest tree seeds]. *Sylwan* 12: 65-72 (in Polish with English abstract).

Tylek, P. 2010. Fizyczne i biologiczne aspekty mechanicznej separacji nasion buka zwyczajnego (*Fagus sylvatica* L.) [Physical and biological aspects of the mechanical separation of seeds of the common beech (*Fagus sylvatica* L.)]. Zeszyty Naukowe Uniwersytetu Rolniczego im. Hugona Kołłątaja w Krakowie. Rozprawy. Zeszyt 344. Wyd. UR, Kraków (in Polish with English abstract).

Upadhaya, K., Pandey, H.N. and Law, P.S. 2007. The Effect of Seed Mass on Germination, Seedling Survival and Growth in *Prunus jenkinsii* Hook.f. & Thoms. *Turkish Journal of Botany* 31: 31-36.

Wesoły, W., Urbański, K. and Barzdajn, W. 1984. Kwitnienie i obradzanie sosny zwyczajnej (*Pinus silvestris* L.) na plantacjach nasiennych [Flowering and Fielding of seed plantations of Scots pine (*Pinus silvestris* L.). *Sylwan* 2: 33-41 (in Polish with English abstract).

Wright, J.W., Pauley, S.S., Polk, R.B. and Jokela, J.J. 1966. Performance of Scotch pine varieties in North Central Region. *Silvae Genetica* 15: 101-110.

Wu, G. and Du, G. 2007. Germination is related to seed mass in grasses (Poaceae) of the eastern Qinghai-Tibetan Plateau, China. *Nordic Journal of Botany* 25(5-6): 361-365.

Załęski, A. 1995. Nasiennictwo leśnych drzew i krzewów iglastych [Management of coniferous forest trees and shrubs for seed production]. Ed. Oficyna Edytorska „Wydawnictwo Świat", Warszawa (in Polish).

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ВЗАИМОЗАВИСИМОСТЬ МЕЖДУ ВСХОЖЕСТЬЮ И ВЫБРАННЫМИ КАЧЕСТВАМИ СЕМЯН СОСНЫ ОБЫКНОВЕННОЙ (*PINUS SYLVESTRIS* L.)

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Резюме

Определена критическая переносная скорость, основные размеры (толщина, ширина и длина), угол скользящего трения, плотность и удельная масса трёх опытных партий семян сосны обыкновенной. На основании органолептического анализа оценен цвет семян, на основании такого анализа заквалифицировано семена в одну из трёх цветовых групп: семена серые, семена чёрные и семена другие. Подсчитан арифметический и геометрический заменяющий диаметр, показатель пропорции, показатель сферичности, удельная масса и густота семян. Далее проведены исследования на прорастание семян, эффекты прорастания контролировано каждые 12 часов, для каждого семени регистрировался коэффициент времени прорастания. Проведено сравнение выше перечисленных свойств и показателей используя тест т для независимых проб, анализа первой вариации и корреляционного анализа. Результаты исследований показали, что увеличение эффективности прорастания семенного материала сосны обыкновенной в небольшой степени зависит от толщины семян (выделено из общей масы семенного материала семена с минимальной толщиной). Сортирование материала при помощи оптического распределителя на данные цветовые группы семян и проведение распределительного процесса отдельно для каждой из них экономно неоправдывается, так как не позволяет получить а ни улучшения эффективности всхожести семян, а ни увеличенитя в значительной степени концентрации всходов. В цветовой группе семена другие, по сравнению с двумя другими группами, отмечено почти в два раза высший процент семян непроросших.

Ключевые слова: семена сосны обыкновенной, физические сойства, всходы