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ANALYSIS OF CORRELATIONS BETWEEN SELECTED PHYSICAL PROPERTIES AND COLOR OF SCOTS PINE (*PINUS SYLVESTRIS* L.) SEEDS

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Abstract

Selected physical properties of Scots pine seeds harvested from five plantations in north-eastern Poland were determined. Seed color was determined in a sensory analysis, and seeds were classified into one of four color groups: black, brown, gray or other. The results of measurements were used to calculate indicators of seed weight and seeds' frictional and geometric properties. Physical attributes and indicators were compared by one-way analysis of variance, correlation analysis and linear regression analysis. The average values of physical properties and indicators characterizing seeds from different color groups were determined at: critical transport velocity – from 7.0 to 7.1 $m \cdot s^{-1}$, thickness – from 1.48 to 1.50 mm, width – from 2.51 to 2.54 mm, length – from 4.32 to 4.46 mm, angle of sliding friction – from 29.1 to 29.8°, weight – from 6.4 to 6.7 mg, coefficient of sliding friction – from 0.56 to 0.58, arithmetic mean diameter – from 2.77 to 2.82 mm, geometric mean diameter – from 2.52 to 2.55 mm, aspect ratio – from 56.91 to 58.64%, sphericity index – from 57.44 to 58.69%, specific weight – from 2.51 to 2.60 $g \cdot m^{-1}$, volume – from 7.90 to 8.24 mm^3 and density – from 0.80 to 0.82 $g \cdot cm^{-3}$. Selected color groups differed only in length, aspect ratio and sphericity index. Seed weight was most highly correlated with the remaining attributes, and the highest value of the correlation coefficient and the equation with the highest value of the coefficient of determination were reported for the correlation between seed weight and thickness.

Symbols:
D_a – arithmetic mean diameter, mm,
D_g – geometric mean diameter, mm,
m – seed weight, mg,
m_D – specific seed weight, $g \cdot m^{-1}$,
R – aspect ratio, %,
SD – standard deviation of trait,

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T, W, L – seed thickness, width and length, mm,
v – critical transport velocity, $m \cdot s^{-1}$,
V – seed volume, mm^3,
x – average value of trait,
x_{max}, x_{min} – maximum and minimum value of trait,
γ – angle of static friction on steel, °,
μ – coefficient of static friction on steel,
ρ – seed density, $g \cdot cm^{-3}$,
Φ – sphericity index, %.

Introduction

Scots pine (*Pinus sylvestris* L.) is a popular species in Central and Northern Europe and Eastern Siberia (WRIGHT et al. 1966, PUCHNIARSKI 2008, TURNA, GUNEY 2009, BRUS et al. 2011, JAWORSKI 2011). It is the predominant species in Poland, and together with other coniferous trees, it occupies nearly 75% of Polish forests (MURAT 2002, PUCHNIARSKI 2008, JAWORSKI 2011). Scots pine thrives on deep soils, sand, loamy sand and light loam, and it is resistant to significant temperature fluctuations in the continental climate. The Baltic countries offer optimal conditions for the growth of the Scots pine (PUCHNIARSKI 2008, JAWORSKI 2011).

Scots pine trees growing in open space begin to produce seeds already at the age of 10 years. Seeds can be harvested from plantations. Plantations are established with the use of drafts of selected cultivars. Mixed seedlings are widely spaced to support interspecific hybridization and the production of high seed yields with improved genetic traits (TROJANKIEWICZ, BURCZYK 2005, PUCHNIARSKI 2008, SIVACIOĞLU, AYAN 2008, SIVACIOĞLU 2010, JAWORSKI 2011). In Poland, high-quality Scots pine seeds are harvested from plantations of 13 to 15-year-old and older trees (WESOŁY et al. 1984).

Seed yield and seed quality are determined by numerous factors, including geographic location, type of habitat, soil type, nutrient availability, genetic traits, age of tree stand, tree size, location of cones in the tree crown, weather conditions during cone and seed development, prevalence of diseases and pests harmful for cones and seeds (KLUCZYŃSKI 1992, ZAŁĘSKI 1995, PALOWSKI 1998, CASTRO 1999, OLEKSYN et al. 2001, BURACZYK 2002, KARLSSON, ÖRLANDER 2002, MOLES, WESTOBY 2003, BODYŁ, ZAŁĘSKI 2005, BODYŁ et al. 2007, SIVACIOĞLU, AYAN 2008, TURNA, GÜNEY 2009, SEVIK et al. 2010, SIVACIOĞLU 2010). Seed quality can be modified during extraction, storage and pre-sowing treatments (ZAŁĘSKI 1995, JANSON, ZAŁĘSKI 1998, ANIŚKO et al. 2006, BODYŁ et al. 2007, ANISZEWSKA, PETRENKO 2012).

Scots pine seeds differ in color (ZAŁĘSKI 1995, SEVIK et al. 2010), and this trait is significantly influenced by cone shape (ANISZEWSKA 2006). The aim of this study was to determine whether Scots pine seeds from various color groups differ in physical attributes, such as critical transport velocity, geometric dimensions, angle of sliding friction and seed weight, as well as indicators calculated based on the above physical properties, including coefficient of static friction, arithmetic and geometric mean diameter, aspect ratio, sphericity index, specific weight, volume and density. The correlations between the physical attributes of Scots pine seeds were determined by the linear regression method to account for the documented influence of seed weight on sprout development and seedling growth (MIKOLA 1980, CASTRO 1999, SHANKAR 2006, UPADHAYA et al. 2007, WU, DU 2007, CASTRO et al. 2008, NORDEN et al. 2009, BURACZYK 2010) and low efficiency of seed separation based on the above trait. Linear regression equations can be used to plan separation processes in conventional cleaning machines (pneumatic and screen separators).

Materials and Methods

The experimental material comprised five batches of Scots pine seeds from extraction plants in Ruciane-Nida and Jedwabno, harvested from five seed regions in three forest regions of north-eastern Poland (Fig. 1). The analyzed seed batches were harvested from the following tree stands:

a) registration No. MP/3/41012/05, region of origin – 456, municipality – Łomża, geographic location – 53.12°N, 22.07°E, forest habitat – fresh mixed forest, age – 13 years (symbol: P-13),

b) registration No. MP/3/41008/05, region of origin – 252, municipality – Mały Płock, geographic location – 53.30°N, 22.07°E, forest habitat – fresh mixed forest, age – 20 years (symbol: P-20),

c) registration No. MP/3/41106/05, region of origin – 103, municipality – Braniewo, geographic location – 54.40°N, 19.83°E, forest habitat – fresh mixed coniferous forest, age – 24 years (symbol: P-24),

d) registration No. MP/3/41102/05, region of origin – 106, municipality – Zalewo, geographic location – 53.77°N, 19.58°E, forest habitat – fresh mixed coniferous forest, age – 31 years (symbol: P-31),

e) registration No. MP/3/41094/05, region of origin – 451, municipality – Wiśniewo, geographic location – 53.08°N, 20.35°E, forest habitat – fresh mixed coniferous forest, age – 38 years (symbol: P-38).

Seed batches were divided by halving (ZAŁĘSKI 1995). The analyzed material was halved, and one half was randomly selected for successive halving. The above procedure was applied to produce samples of around 100 seeds each. The analyzed seed batches had the following size: P-13 – 107, P-20 – 106, P-24 – 106, P-31 – 107, P-38 – 105.

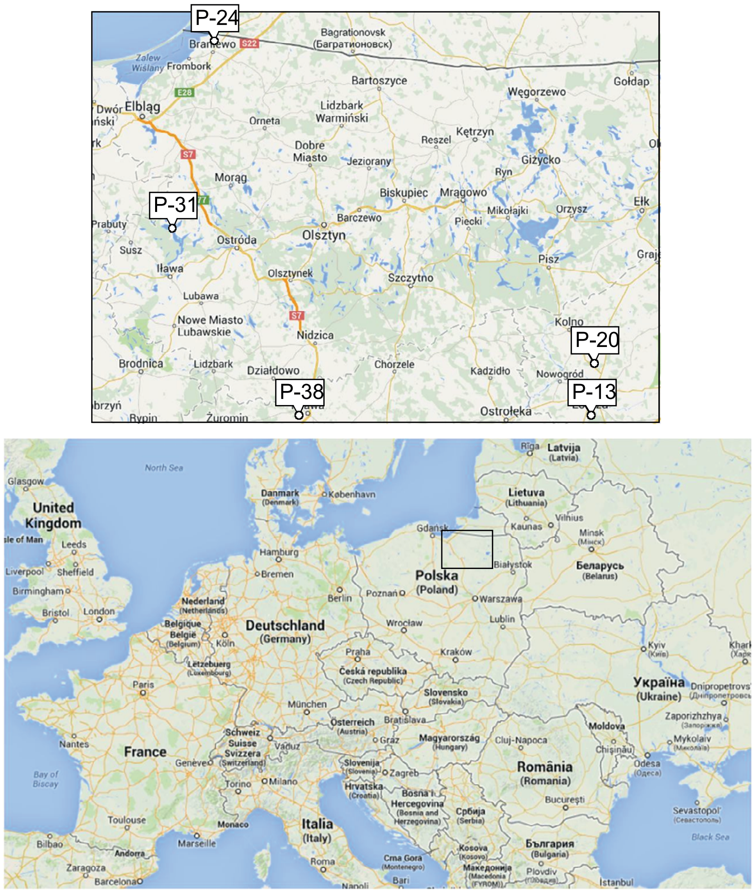

Fig. 1. Geographic location of Scots pine seed plantations

Critical transport velocity was determined in the Petkus K-293 pneumatic classifier, seed dimensions were determined with the use of 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 equipped with a steel friction plate (GPS – Ra = 0.65 µm), 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) and KALINIEWICZ and POZNAŃSKI (2013).

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

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

– coefficient of static friction, based on the following general formula:

$$\mu = \tan \gamma \tag{1}$$

– arithmetic and geometric mean diameter, aspect ratio and sphericity index (MOHSENIN 1986):

$$D_a = \frac{T + W + L}{3} \tag{2}$$

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

$$R = \frac{W}{L} \cdot 100 \tag{4}$$

$$\Phi = \frac{(T \cdot W \cdot L)^{1/3}}{L} \cdot 100 \tag{5}$$

– specific weight (KALINIEWICZ 2013):

$$m_D = \frac{m}{D_g} \tag{6}$$

– volume, based on the coefficient determined experimentally by KALINIEWICZ et al. (2012b):

$$V = 0.487 \cdot T \cdot W \cdot L \tag{7}$$

– density:

$$\rho = \frac{m}{V} \tag{8}$$

The results of measurements and calculations were processed in the Statistica v. 10 application with the use of general statistical procedures, including one-way analysis of variance, correlation analysis and linear regression analysis (RABIEJ 2012). Statistical calculations were performed at the significance level of 0.05.

Results and Discussion

The parameters of the analyzed seeds are presented in Table 1. The lowest average values of critical transport velocity, seed thickness, length and weight were reported in batch P-20. Consequently, seeds from the above batch were also characterized by the lowest average values of arithmetic and geometric mean diameter, specific weight and volume. Seeds from batch P-13 were characterized by the greatest plumpness and the highest average values of critical transport velocity, thickness, width, weight, arithmetic and geometric mean diameter, specific weight, volume and density. The average values of the analyzed parameters are characteristic of Polish Scots pine seeds (CZERNIK 1983a, 1983b, WESOŁY et al. 1984, ZAŁĘSKI 1995, TYLEK 1998, BODYŁ, ZAŁĘSKI 2005, BODYŁ et al. 2007, BURACZYK 2010, KALINIEWICZ et al. 2011, 2013). In line with the observations of OLEKSYN et al. (2001) and MOLES and WESTOBY (2003), who examined the correlations between seed weight and local climate, the analyzed seeds were somewhat lighter than the material originating from South Europe (MIKOLA 1980, CASTRO 1999, CASTRO et al. 2008, SIVACIOĞLU, AYAN 2008, CARRILLO-GAVILÁN et al. 2010, SEVIK et al. 2010, SIVACIOĞLU 2010), but heavier than the seeds harvested in northern regions of the continent (MIKOLA 1980, KARLSSON, ÖRLANDER 2002).

Table 1

Variations in physical properties and the calculated indicators of the analyzed batches of Scots pine seeds in view of significant differences in the studied traits

Property/ /indicator	Batch of seeds				
	P-13 $x \pm SD$	P-20 $x \pm SD$	P-24 $x \pm SD$	P-31 $x \pm SD$	P-38 $x \pm SD$
v	7.18 ± 0.47^{a}	6.82 ± 0.39^{b}	7.06 ± 0.49^{a}	7.13 ± 0.46^{a}	7.07 ± 0.42^{a}
T	1.53 ± 0.14^{a}	1.45 ± 0.14^{c}	1.50 ± 0.15^{ab}	1.48 ± 0.16^{bc}	1.48 ± 0.12^{bc}
W	2.57 ± 0.26^{a}	2.50 ± 0.24^{ab}	2.56 ± 0.24^{a}	2.51 ± 0.23^{ab}	2.48 ± 0.20^{b}
L	4.53 ± 0.44^{a}	4.19 ± 0.42^{c}	4.54 ± 0.38^{a}	4.37 ± 0.45^{b}	4.25 ± 0.40^{c}
γ	27.4 ± 3.87^{d}	30.1 ± 4.00^{b}	31.2 ± 3.02^{a}	28.4 ± 2.87^{c}	29.3 ± 3.49^{bc}
m	7.1 ± 1.41^{a}	6.0 ± 1.30^{c}	6.9 ± 1.53^{a}	6.5 ± 1.59^{b}	6.2 ± 1.23^{bc}
μ	0.52 ± 0.09^{d}	0.58 ± 0.10^{b}	0.61 ± 0.07^{a}	0.54 ± 0.07^{c}	0.56 ± 0.08^{bc}
D_a	2.87 ± 0.20^{a}	2.71 ± 0.22^{c}	2.87 ± 0.21^{a}	2.79 ± 0.23^{b}	2.74 ± 0.19^{bc}
D_g	2.60 ± 0.17^{a}	2.47 ± 0.19^{c}	2.59 ± 0.19^{a}	2.53 ± 0.20^{b}	2.50 ± 0.17^{bc}
R	57.10 ± 7.70^{bc}	60.01 ± 6.28^{a}	56.62 ± 4.74^{c}	57.81 ± 5.79^{bc}	58.80 ± 5.90^{ab}
Φ	57.73 ± 4.31^{b}	59.25 ± 4.13^{a}	57.22 ± 3.35^{b}	58.19 ± 3.94^{ab}	58.99 ± 3.64^{a}
m_D	2.73 ± 0.40^{a}	2.41 ± 0.35^{c}	2.62 ± 0.42^{b}	2.52 ± 0.43^{bc}	2.47 ± 0.34^{c}
V	8.70 ± 1.73^{a}	7.50 ± 1.74^{c}	8.61 ± 1.87^{a}	8.03 ± 1.98^{b}	7.67 ± 1.56^{bc}
ρ	0.83 ± 0.10^{a}	0.81 ± 0.07^{ab}	0.80 ± 0.06^{b}	0.81 ± 0.07^{ab}	0.81 ± 0.07^{ab}

$^{a, b, c, d}$ – different letters in the superscript point to significant differences in the value of an property (indicator) across seed batches

The average values of the analyzed physical attributes were determined at:
- critical transport velocity – from 6.82 m · s^{-1} (P-20) to 7.18 m · s^{-1} (P-13),
- thickness – from 1.45 mm (P-20) to 1.53 mm (P-13),
- width – from 2.48 mm (P-38) to 2.57 mm (P-13),
- length – from 4.19 mm (P-20) to 4.54 mm (P-24),
- angle of sliding friction – from 27.4^{o} (P-13) to 31.2^{o} (P-24),
- weight – from 6.0 mg (P-20) to 7.1 mg (P-13).

The average values of the coefficient of sliding friction ranged from 0.52 (P-13) to 0.61 (P-24). Similar values were reported by OYELADE et al. (2005) in African star apple seeds. The average values of arithmetic and geometric mean diameter were determined in the range of 2.71 mm to 2.87 mm and 2.47 mm to 2.60 mm, respectively. They were somewhat higher than the values noted by KALINIEWICZ et al. (2013) in a study of qualified and source-identified seeds. No significant differences were reported between the remaining indicators. The average values of the aspect ratio ranged from 56.62% (P-24) to 60.01% (P-20). Similar results were reported by CZERNIK (1983a) and TYLEK (1998). The average values of the sphericity index (57.22% to 59.25%) of the analyzed Scots pine seeds were similar to those observed in wheat seeds (KALKAN, KARA 2011, KALINIEWICZ 2013, MARKOWSKI et al. 2013), African star apple seeds (OYELADE et al. 2005) and cocoa beans (BART-PLANGE, BARYEH 2003).

The analyzed material comprised 34.6% to 51.9% black seeds, 10.3% to 29.2% brown seeds, 7.5% to 24.5% gray seeds and 9.4% to 36.4% seeds from the "other" color group (Fig. 2). The share of differently colored seeds varied significantly even in material harvested from the same source. Significant variations in seed color were also reported by ANISZEWSKA (2006) who analyzed the influence of cone shape on seed parameters. The share of gray seeds in the

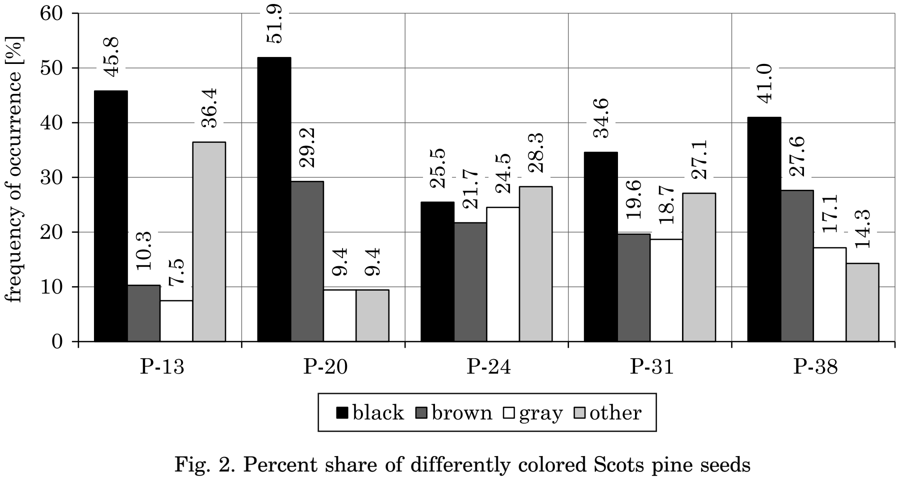

Fig. 2. Percent share of differently colored Scots pine seeds

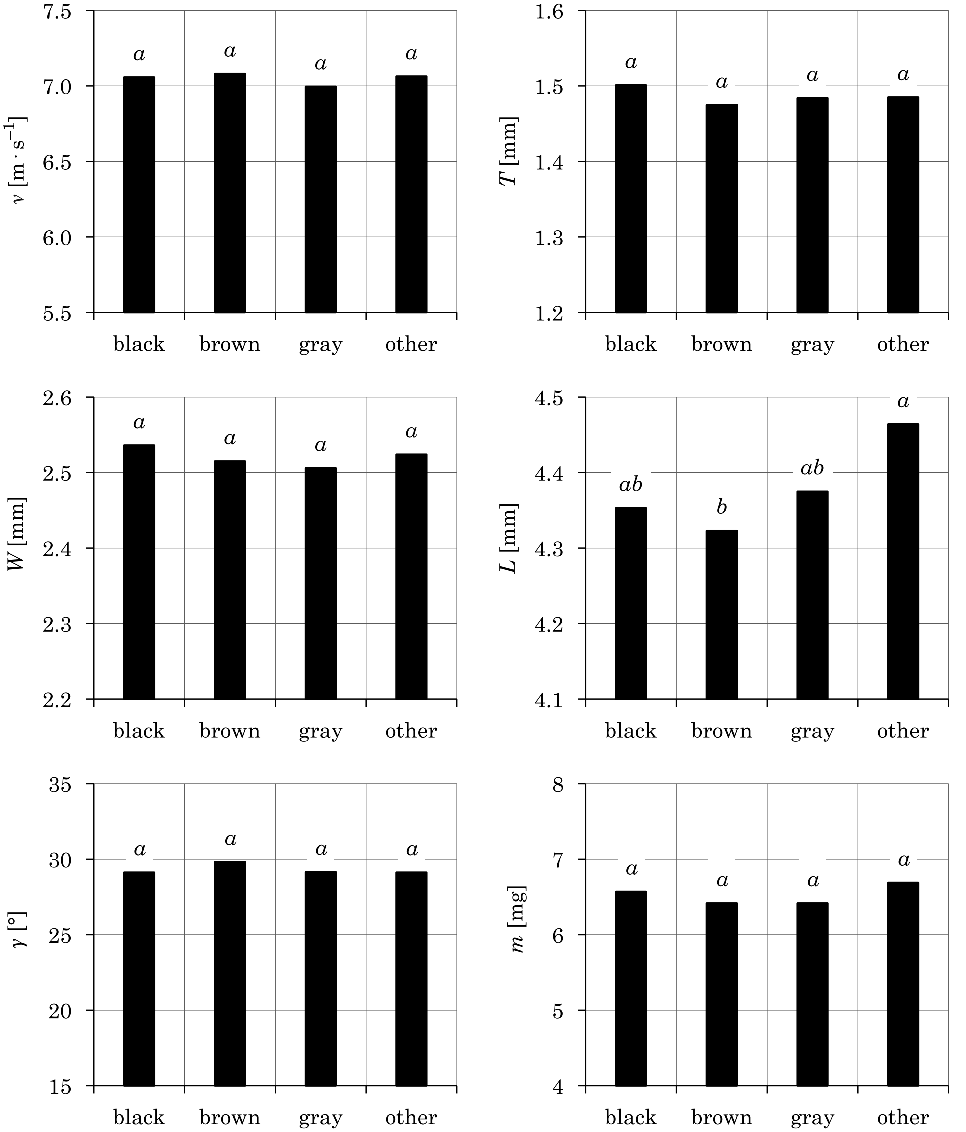

Fig. 3. Significance of differences between physical properties of Scots pine seeds: *a, b* – different letters indicate significant differences in the value of an property across the analyzed color groups

analyzed material was similar to that noted in Turkish seeds by SEVIK et al. (2010).

The physical attributes and the indices calculated for seeds from different color groups are compared in Figures 3 and 4. Black, brown, gray and other seeds did not differ significantly with regard to their critical transport velocity,

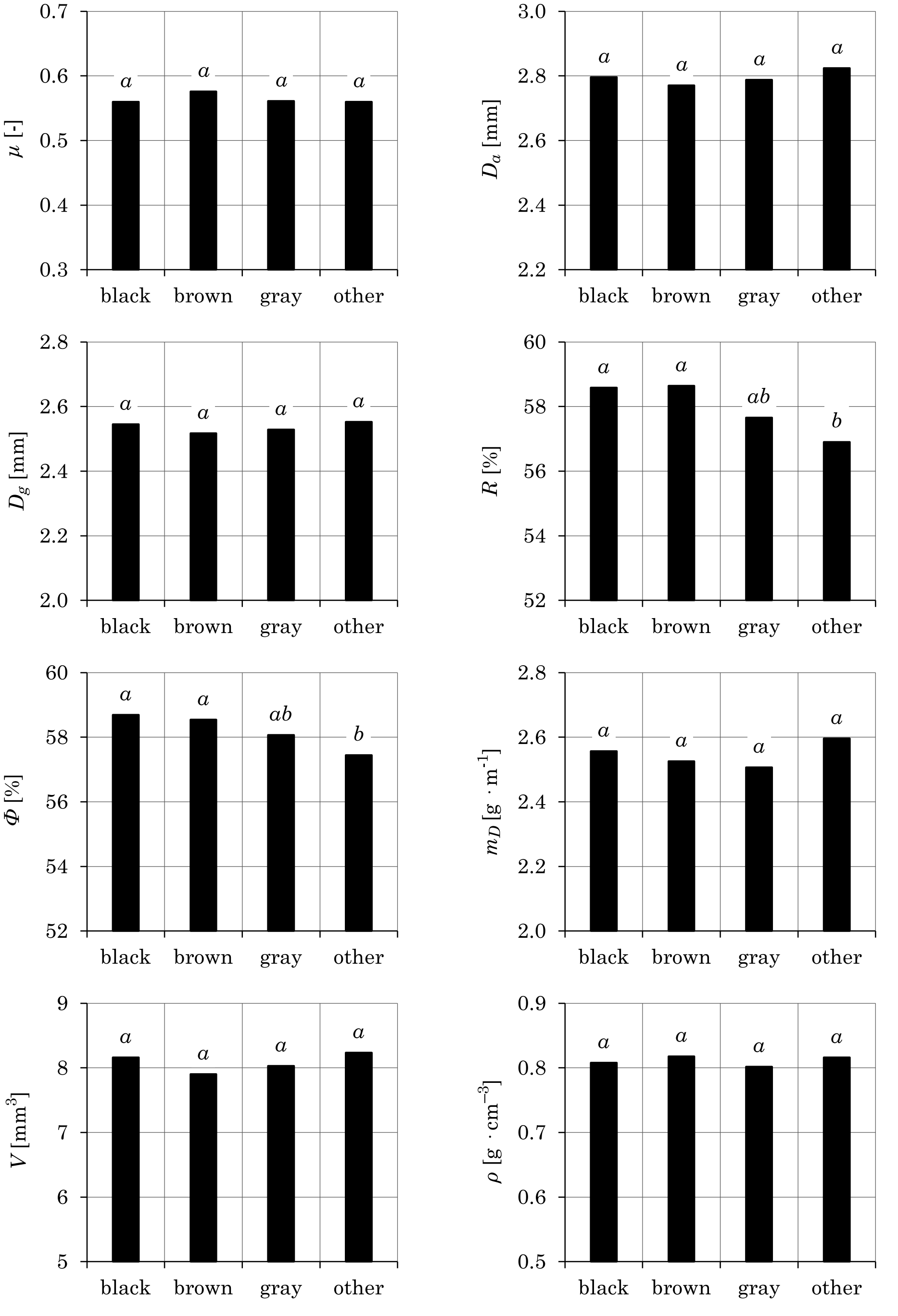

Fig. 4. Significance of differences between the calculated indicators of Scots pine seeds: *a, b* – different letters indicate significant differences in the value of an indicator across the analyzed color groups

thickness, width, angle of sliding friction, weight, coefficient of sliding friction, arithmetic and geometric mean diameter, specific weight, volume and density. Local differences were reported between the remaining parameters (length) and indicators (aspect ratio and sphericity index), mainly between brown seeds and seeds from the "other" color group. Gray seeds did not differ from the remaining color groups.

A linear correlation analysis (Tab. 2) of selected attributes, which can be potentially applied in separation processes, indicates that the angle of sliding friction and seed density were least correlated, and seed weight was most correlated with the remaining attributes in all color groups. The highest values of the correlation coefficient were noted between seed thickness and seed weight in all groups (from 0.751 in the "other" color group to 0.802 in gray seeds). Seed width was also highly correlated with seed weight (average of

Table 2

Pearson's coefficients of correlation between selected properties of Scots pine seeds

Color	Property	T	W	L	γ	m	ρ
Black	v	**0.699**	**0.362**	**0.187**	**–0.222**	**0.591**	**0.122**
	T	1	**0.548**	**0.325**	**–0.169**	**0.775**	–0.095
	W		1	**0.369**	–0.043	**0.736**	**–0.255**
	L			1	0.004	**0.658**	**–0.184**
	γ				1	–0.106	–0.075
	m					1	**0.137**
Brown	v	**0.594**	**0.344**	**0.205**	–0.112	**0.556**	0.130
	T	1	**0.629**	**0.353**	–0.145	**0.767**	**–0.221**
	W		1	**0.350**	–0.012	**0.709**	**–0.277**
	L			1	0.066	**0.657**	**–0.269**
	γ				1	–0.075	–0.080
	m					1	0.109
Gray	v	**0.658**	**0.296**	0.102	**–0.251**	**0.561**	**0.266**
	T	1	**0.510**	**0.339**	–0.163	**0.802**	0.046
	W		1	**0.452**	–0.112	**0.692**	–0.208
	L			1	0.093	**0.653**	–0.177
	γ				1	–0.170	–0.209
	m					1	**0.269**
Other	v	**0.722**	**0.347**	0.085	–0.162	**0.547**	0.060
	T	1	**0.513**	**0.254**	–0.069	**0.751**	–0.106
	W		1	**0.303**	0.166	**0.730**	**–0.245**
	L			1	**0.182**	**0.594**	**–0.205**
	γ				1	0.113	–0.066
	m					1	0.147
All	v	**0.667**	**0.349**	**0.175**	**–0.200**	**0.577**	**0.150**
	T	1	**0.557**	**0.336**	**–0.166**	**0.779**	**–0.099**
	W		1	**0.378**	–0.049	**0.723**	**–0.249**
	L			1	0.028	**0.657**	**–0.206**
	γ				1	**–0.113**	**–0.094**
	m					1	**0.154**

Bold font indicates that the correlation coefficient has exceeded critical value

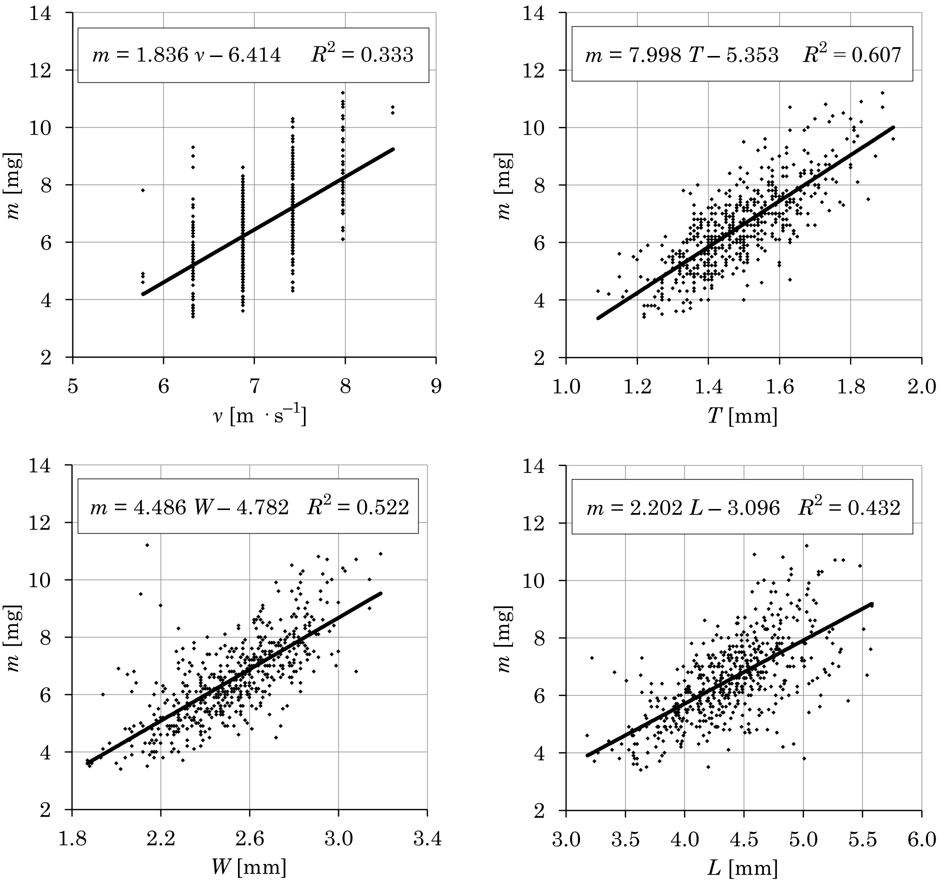

Fig. 5. Correlations between the weight of Scots pine seeds and critical transport velocity, seed thickness, width and length

0.723). It was similar to that reported in Turkish seeds (SIVACIOĞLU 2010), but lower than that determined by BURACZYK (2010). Seed weight and seed width were also highly correlated in Aleppo pine (MATZIRIS 1998) and Anatolian black pine seeds (SIVACIOĞLU, AYAN 2010). Relatively strong correlations were reported between seed thickness, critical transport velocity and width, and between seed weight and length in all color groups.

In view of the reported results and the fact that the analyzed color groups did not differ in their germination capacity (KALINIEWICZ et al. 2013), the correlations between the examined traits were determined collectively for all seeds. Significant correlations between seed weight and the remaining parameters were presented on account of the documented influence of seed weight on seed germination and seedling development in the first year of cultivation

(MIKOLA 1980, SABOR 1984, BONFIL 1998, CASTRO 1999, SEIWA 2000, KHAN, SHANKAR 2001, KHAN 2004, PARKER et al. 2006, SHANKAR 2006, QUERO et al. 2007, BURACZYK 2010). Linear regression equations for the analyzed Scots pine seeds are presented in Figure 5. The highest value of the coefficient of determination of 0.607 was noted in the equation describing the relationship between seed weight and thickness. High values of the coefficient of determination were also reported in equations analyzing the correlations between seed weight and seed dimensions (width and length). The above correlations were characterized by good fit to empirical data for biological material, which implies that they can be effectively used to plan separation processes of Scots pine seeds. The results of the analysis can be applied to estimate the working parameters of seed separation equipment and produce fractions with specific seed weight. This is an important practical consideration because Scots pine seeds are generally cleaned and sorted with the involvement of screen and pneumatic devices and combinations thereof (ZAŁĘSKI 1995, SARNOWSKA, WIĘSIK 1998).

For the needs of this analysis, it was assumed that Scots pine seeds comprise light (m < 5.9 mg), medium (m = 5.9÷7.0 mg) and heavy seeds (m > 7.0 mg). The distribution of seed fractions sorted based on seed thickness is presented in a histogram in Figure 6. A sieve separator incorporating a mesh screen with longitudinal openings measuring ≠ 1.4 mm can be used to separate 68% light seeds, 21.3% medium seeds and only 2.8% heavy seeds. A mesh screen with longitudinal openings measuring ≠ 1.5 mm can be installed in the

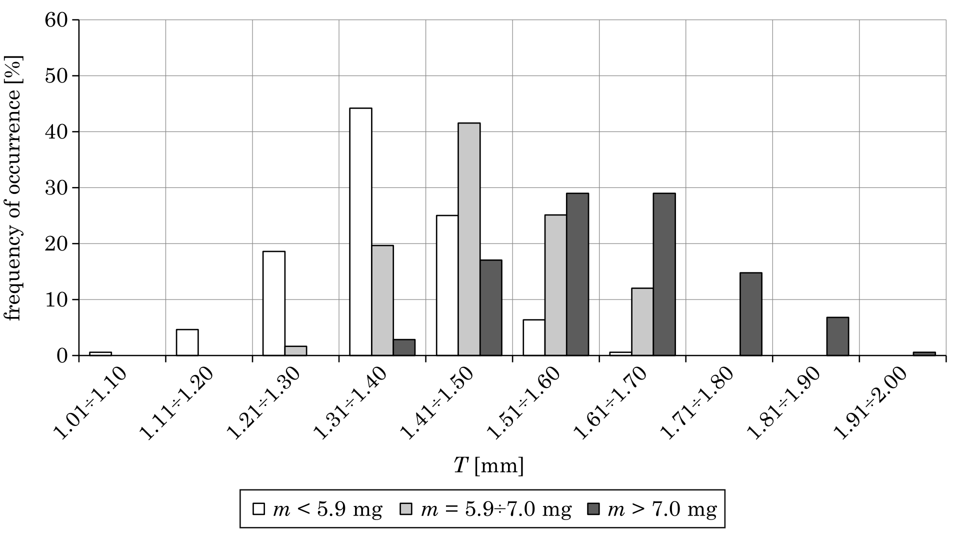

Fig. 6. Thickness of Scots pine seeds

collecting bucket to separate the heaviest seed fractions. The proposed approach enables the separation of 80.2% heavy seeds, 37.1% medium seeds and only 7% light seeds.

Conclusions

1. Seeds harvested from seed plantations are characterized by varied proportions of differently colored material. The analyzed batches contained mostly black seeds (25.5% to 51.9%), whereas the share of the remaining color groups (brown, gray and other) varied from 7.5% to 36.4%.

2. Black, brown, gray and other Scots pine seeds did not differ significantly in their physical attributes or the values of the calculated indicators. Significant variations between color groups were noted only with regard to seed length, aspect ratio and sphericity index. No significant differences in physical attributes and indicators were observed between grey seeds and other color groups.

3. The most highly correlated physical attributes of Scots pine seeds were thickness and weight, and the least correlated traits were seed length and angle of sliding friction (although critical values were insignificantly exceeded in gray seeds).

4. Scots pine seeds should be sorted with the use of a sieve separator equipped with mesh screens with longitudinal openings (sorting based on seed thickness) and/or mesh screens with round openings (sorting based on seed width). The above equipment effectively separates the majority of light or heavy seeds, and it can be used to improve the separation capacity and separation rate of seeds.

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