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VARIABILITY IN AND CORRELATIONS AMONG SELECTED PHYSICAL PROPERTIES OF EUROPEAN LARCH (*LARIX DECIDUA* MILL.) SEEDS

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Abstract

Selected physical attributes of European larch seeds harvested from 2 seed plantations and 2 commercial seed stands in north-eastern Poland were determined. The physical properties of seeds were measured, and the results were used to calculate indicators of seed weight and the frictional and geometric properties of seeds. Physical attributes and indicators were compared by Student's t-test for independent samples, analysis of variance, correlation analysis and linear regression analysis. The average values of physical properties and indicators were determined at: critical transport velocity – from 5.93 to 6.13 $m \cdot s^{-1}$, thickness – from 1.25 to 1.43 mm, width – from 2.29 to 2.71 mm, length – from 3.71 to 4.57 mm, angle of sliding friction – from 27.85 to 31.98^o, weight – from 4.03 to 6.14 mg, coefficient of sliding friction – from 0.54 to 0.63, arithmetic mean diameter – from 2.42 to 2.90 mm, geometric mean diameter – from 2.20 to 2.60 mm, aspect ratio – from 59.60 to 62.38%, sphericity index – from 57.27 to 59.40%, specific weight – from 1.81 to 2.33 $g \cdot m^{-1}$, volume – from 4.60 to 7.59 mm^3 and density – from 0.82 to 0.91 $g \cdot cm^{-3}$. The material harvested in seed plantations differed from seeds from commercial seed stands in all parameters, excluding critical transport velocity. Seed weight was most correlated with the remaining parameters. The highest value of the correlation coefficient and the equation with the highest value of the coefficient of determination were reported for the dependence between seed weight and seed length. Seed weight was also relatively highly correlated with seed width, therefore, the use of mesh screens with round openings and/or cylindrical grain graders is recommended in seed sorting processes.

Symbols:
D_a – arithmetic mean diameter, mm,
D_g – geometric mean diameter, mm,
m – seed weight, mg,
m_D – specific seed weight, $g \cdot m^{-1}$,

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R – aspect ratio, %,
SD – standard deviation of trait,
T, W, L – seeds thickness, width and length, mm,
v – critical transport velocity of seeds, $m \cdot s^{-1}$,
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 of seeds on steel, °,
μ – coefficient of static friction of seeds on steel,
ρ – seed density, $g \cdot cm^{-3}$,
Φ – sphericity index, %.

Introduction

Larch is a deciduous conifer that differs from other members of the pine family in that it sheds its needles in winter. The European larch (*Larix decidua* Mill.) is well adapted to the continental climate. In Poland, the optimal habitat for the species is found in the High Tatra Mountains. The European larch occurs sporadically in all Polish regions, mostly in artificial stands. The European larch and other larch species occupy approximately 2% of total forest area in Poland. The European larch is one of the most light-demanding trees of the temperate climate. The taxon has medium soil requirements, and it thrives on deep and medium-compact soils. The European larch grows best on soils with moderate moisture content and does not tolerate significant fluctuations in soil moisture (MURAT 2002, PUCHNIARSKI 2008, JAWORSKI 2011).

The European larch is a fast-growing species that can reach the height of 4.5 m already at the age of 5 years. The increase in height ends at the age of 15–25 years. Seeds can be harvested already from 15-year-old trees that grow in open spaces, whereas dense stands begin to produce seeds at the age of around 30 years. High seed yields are noted every 2–3 years or even every 6 years. Seeds mature in October-November, and cones are harvested between November and February before they release seeds (ZAŁĘSKI 1995, MURAT 2002, JAWORSKI 2011). In the natural habitat, seeds are released from the cone after repeated bending and flexing of the scales, and in extraction plants, seeds are removed from cones by a combination of thermal and mechanical extraction methods (ZAŁĘSKI 1995, ANISZEWSKA 2009, 2010). European larch seeds with moisture content of around 7% are suitable for short-term storage, but the moisture content of material intended for longer storage has to be further reduced (ZAŁĘSKI 1995).

European larch seeds do not require pre-sowing treatment, but soaking in water improves seed germination (ZAŁĘSKI 1995). According to the literature, (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, CASTRO et al. 2008, BURACZYK 2010), seed weight is one of the main physical properties that affect germination efficiency of most seed species. Seeds are difficult to sort based on this attribute. The correlations among seed weight and other physical properties were analyzed in this study, and the results were used to plan seed sorting processes.

The objective of this study was to determine the variations in and the correlations among the physical properties and the calculated indicators of European larch seeds obtained from seed plantations and commercial seed plants to increase the efficiency of seed sorting processes.

Materials and Methods

The experimental material comprised four batches of European larch from seed extraction plants in Jedwabno and Ruciane-Nida. Seeds were harvested in 2010 from selected seed stands and seed plantations in two forest regions of north-eastern Poland. The analyzed batches were harvested from the following tree stands:

a) registration No. MP/3/41221/05, region of origin – 157, municipality – Gardeja, geographic location – 53.67°N, 18.90°E, forest habitat – fresh mixed forest, age – 12 years (symbol: PN-12);
b) 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 – 25 years (symbol: PN-25);
c) registration No. MP/2/30944/05, region of origin – 202, municipality – Kowale Oleckie, geographic location 54.10°N, 22.25°E, forest habitat – fresh forest, age – 129 years (symbol: WDN-129);
d) registration number – MP/2/30988/05, region of origin – 206, municipality – Ruciane Nida, geographic location – 53.65°N, 21.53°E, forest habitat – fresh mixed forest, age – 150 years (symbol: WDN-150).

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-12 – 101, P-25 – 105, WDN-129 – 109, WDN-150 – 120.

Critical transport velocity of European larch seeds 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) and KALINIEWICZ and POZNAŃSKI (2013).

The following indicators were determined for every seed:

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

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

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

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

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

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

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

– specific weight (KALINIEWICZ 2013):

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

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

$$V = 0.42 \cdot T \cdot W \cdot L \tag{7}$$

– density:

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

The results were processed with the use of Statistica PL v. 10 application based on general statistical procedures, including Student's t-test for independent samples, one-way ANOVA, 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 seed thickness, width, length and mass, arithmetic and geometric mean diameter, specific weight and volume were reported in batch PN-25. The lowest seed plumpness was noted in batch PN-25, and the highest – in batch WDN-150. Seeds from selected seed stands were generally larger and heavier than the material harvested from seed plantations. Critical transport velocity values were generally consistent with those cited by KALINIEWICZ et al. (2012a) and somewhat higher than those noted by CZERNIK (1983b) and TYLEK (1999, 2004). The average seed dimensions and seed weight values were comparable to those reported by CZERNIK (1983a), TYLEK (2004) and KALINIEWICZ et al. (2012a). European larch seeds are similar in width to lodgepole pine seeds (JOHNSON et al. 2003), the seeds of selected rye varieties (ZDYBEL et al. 2009, KUSIŃSKA et al. 2010), oats, barley (HEBDA, MICEK 2007) and common

Table 1

Variations in the physical properties and the calculated indicators of the analyzed batches of European larch seeds in view of significant differences in the examined traits

Property/ indicator	Batch of seeds			
	PN-12 $\bar{x} \pm$ SD	PN-25 $\bar{x} \pm$ SD	WDN-129 $\bar{x} \pm$ SD	WDN-150 $\bar{x} \pm$ SD
v	6.13 ± 0.74^{a}	6.02 ± 0.47^{ab}	6.06 ± 0.57^{ab}	5.93 ± 0.57^{b}
T	1.29 ± 0.15^{c}	1.25 ± 0.14^{d}	1.37 ± 0.16^{b}	1.43 ± 0.16^{a}
W	2.43 ± 0.29^{c}	2.29 ± 0.30^{d}	2.62 ± 0.32^{b}	2.71 ± 0.29^{a}
L	3.90 ± 0.42^{c}	3.71 ± 0.47^{d}	4.36 ± 0.53^{b}	4.57 ± 0.62^{a}
γ	27.85 ± 5.79^{b}	31.52 ± 5.75^{a}	31.18 ± 6.30^{a}	31.98 ± 5.90^{a}
m	4.75 ± 1.51^{c}	4.03 ± 1.09^{d}	5.67 ± 1.48^{b}	6.14 ± 1.65^{a}
μ	0.54 ± 0.13^{b}	0.62 ± 0.15^{a}	0.62 ± 0.16^{a}	0.63 ± 0.14^{a}
D_a	2.54 ± 0.24^{c}	2.42 ± 0.27^{d}	2.78 ± 0.29^{b}	2.90 ± 0.31^{a}
D_g	2.30 ± 0.22^{c}	2.20 ± 0.23^{d}	2.50 ± 0.25^{b}	2.60 ± 0.25^{a}
R	62.38 ± 6.13^{a}	62.16 ± 5.89^{a}	60.43 ± 6.60^{b}	59.60 ± 5.52^{b}
Φ	59.11 ± 3.55^{a}	59.40 ± 3.18^{a}	57.48 ± 3.76^{b}	57.27 ± 3.96^{b}
m_D	2.03 ± 0.51^{b}	1.81 ± 0.36^{c}	2.24 ± 0.41^{a}	2.33 ± 0.46^{a}
V	5.25 ± 1.43^{c}	4.60 ± 1.42^{d}	6.74 ± 2.01^{b}	7.59 ± 2.13^{a}
ρ	0.91 ± 0.16^{a}	0.90 ± 0.15^{ab}	0.86 ± 0.13^{b}	0.82 ± 0.13^{c}

a, b, c, d – different letters point to significant differences in the value of a property (indicator) across seed batches

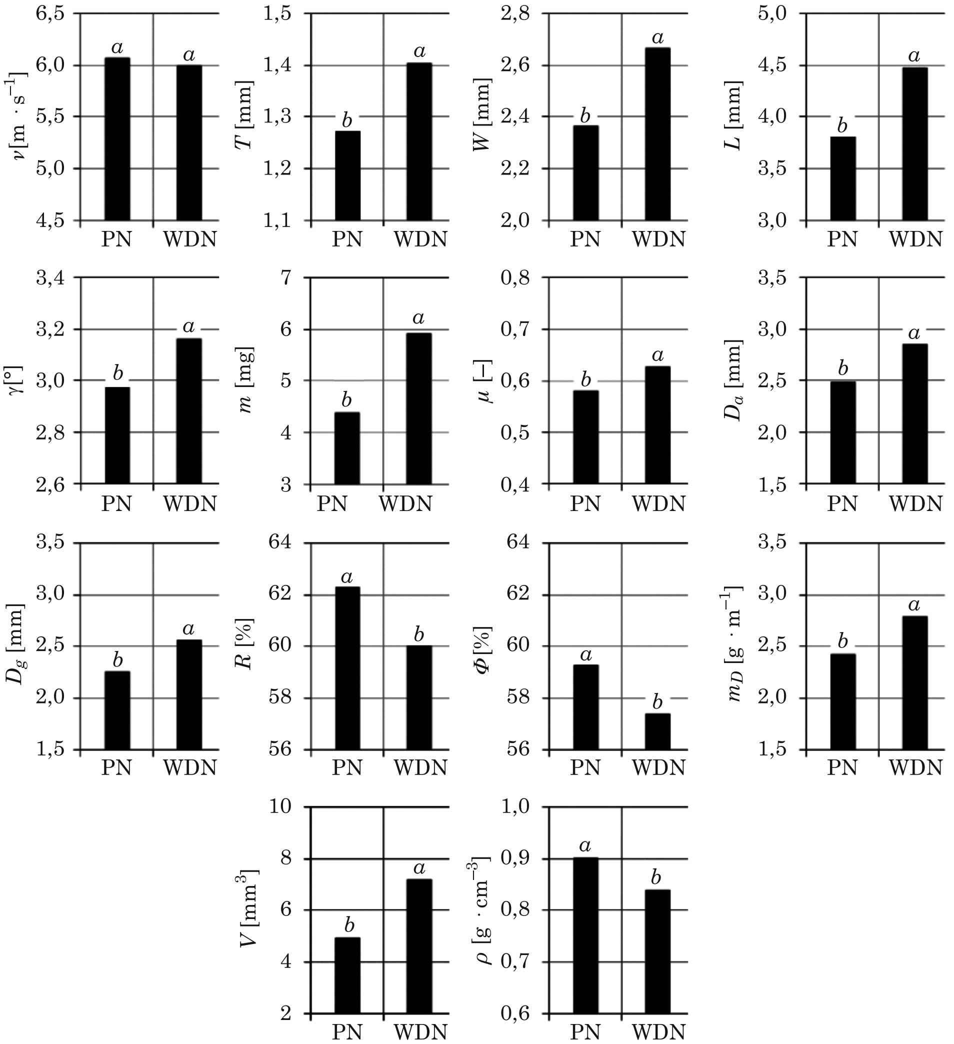

Fig. 1. Significance of differences among physical properties and indicators of European larch seeds: *a, b* – different letters indicate significant differences in the value of a property (indicator) across the analyzed seed batches

flax (PRADHAN et al. 2010). The average angle of sliding friction of European larch seeds, estimated in the range of 28° to 32°, resembles that of spelt seeds (CHOSZCZ et al. 2010) and sorry seeds (OMOBUWAJO et al. 2000). European larch seeds were similar to common flax seeds in their arithmetic and geometric mean diameter (PRADHAN et al. 2010), whereas their sphericity index resembled that of wheat (KALKAN, KARA 2011, KALINIEWICZ 2013, MARKOWSKI et al. 2013), *Chrysophyllum albidum* (OYELADE et al. 2005) and cocoa seeds (BART-PLANGE, BARYEH 2003).

The physical properties and the calculated indicators of seeds harvested from seed plantations (PN) and selected seed stands (WDN) are compared in Figure 1. The analyzed seeds differed in all parameters, excluding critical transport velocity. WDN seeds were more plump and were characterized by significantly greater thickness, width, length, weight, arithmetic and geometric mean diameter, specific weight and volume. They were also characterized by higher average angle of sliding friction and coefficient of sliding friction. The values of the aspect ratio and the sphericity index were lower in WDN seeds, which indicates that seeds harvested from seed stands were more slender that the material collected from seed plantations. The above also contributed to the lower density of WDN seeds.

A linear correlation analysis (Table 2) of selected properties that can be potentially applied in separation processes indicates that the angle of sliding friction was least correlated with the remaining attributes. Similar correlations with the angle of sliding friction and other physical parameters were observed in Scots pine seeds (KALINIEWICZ et al. 2011). Seed weight was most correlated with the remaining physical attributes, and the highest value of the correlation coefficient (0.823) was noted in a comparison of seed weight and seed length. The weight of European larch seeds was also significantly influenced by seed width and thickness. Similarly high correlation coefficients were noted in fir (CZERNIK 1993), Scots pine (SIVACIOĞLU 2010), Aleppo pine (MATZIRIS 1998) and black pine seeds (SIVACIOĞLU, AYAN 2010).

Table 2

Pearson's coefficients of correlation between selected parameters of European larch seeds

Grupa nasion	Property	T	W	L	γ	m	ρ
PN	v	**0.313**	**0.143**	0.106	-0.108	**0.580**	**0.595**
	T	1	**0.511**	**0.542**	**-0.196**	**0.603**	**-0.314**
	W		1	**0.702**	-0.081	**0.756**	-0.119
	L			1	-0.109	**0.721**	**-0.193**
	γ				1	**-0.145**	0.001
	m					1	**0.337**
WDN	v	**0.231**	0.074	0.076	**-0.214**	**0.460**	**0.556**
	T	1	**0.404**	**0.437**	**-0.306**	**0.566**	**-0.437**
	W		1	**0.714**	**-0.231**	**0.737**	**-0.330**
	L			1	**-0.226**	**0.800**	**-0.276**
	γ				1	**-0.343**	-0.003
	m					1	0.092
Total	v	**0.220**	0.066	0.039	**-0.169**	**0.423**	**0.575**
	T	1	**0.546**	**0.580**	**-0.173**	**0.655**	**-0.421**
	W		1	**0.772**	-0.075	**0.796**	**-0.291**
	L			1	-0.066	**0.823**	**-0.309**
	γ				1	**-0.155**	-0.035
	m					1	0.078

Values in bold indicate that the critical value of the correlation coefficient has been exceeded

Relatively high correlation coefficients were reported among seed dimensions and between seed weight and critical transport velocity. The noted values are somewhat different from those observed in European larch seeds by CZERNIK (1983a, 1983b), but they are similar to those reported in Scots pine (TURNA, GÜNEY 2009, KALINIEWICZ et al. 2011), black pine (SIVACIOĞLU, AYAN 2010), fir (CZERNIK 1993) and small-leaved lime seeds (KALINIEWICZ, POZNAŃSKI 2013).

According to the literature, seed weight influences seed germination and seedling development in the first year of life (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, CASTRO et al. 2008, BURACZYK 2010), and for this reason, only the dependences among seed weight and the remaining physical properties of European larch seeds were determined in this study (Table 3). In the correlation analysis, the equation with the highest value of the coefficient of determination (0.678) was reported in a comparison of seed weight and seed length. Relatively high values of the coefficient of determination were also noted for equations of seed weight as a function of the remaining parameters (width and thickness). It should also be noted that the above correlations were characterized by good fit to empirical data, implying that they can be effectively used to plan separation processes of European larch seeds. The results of the analysis can be applied to estimate the working parameters of seed separation machines based on aerodynamic and geometric attributes, mostly mesh screens (ZAŁĘSKI 1995, SARNOWSKA, WIĘSIK 1998).

Table 3

Correlations among seed weight and selected physical properties of European larch seeds

Equation	Coefficient of determination R^2	Standard error of estimate
$m = 1.190v - 1.985$	0.179	1.513
$m = 6.513T - 3.542$	0.429	1.261
$m = 3.904W - 4.657$	0.634	1.011
$m = 2.199L - 3.957$	0.678	0.948
$m = 0.042\gamma - 6.482$	0.024	1.649

For the needs of this analysis, it was assumed that European larch seeds comprised light (m < 4.5 mg), medium (m = 4.5÷6.0 mg) and heavy seeds (m > 6.0 mg). The distribution of seed fractions sorted based on seed thickness, width and length is presented in a histogram in Figure 2. The results indicate that seeds can be separated effectively based on differences in their width and length. A sieve separator incorporating a mesh screen with round openings measuring 2.6 mm in diameter can be used to separate 88% light seeds, 41% medium seeds and only 7% heavy seeds. A cylindrical grader with indentations measuring 4.4 mm in diameter can potentially separate approximately 80% heavy seeds, 25% medium seeds and 2% light seeds.

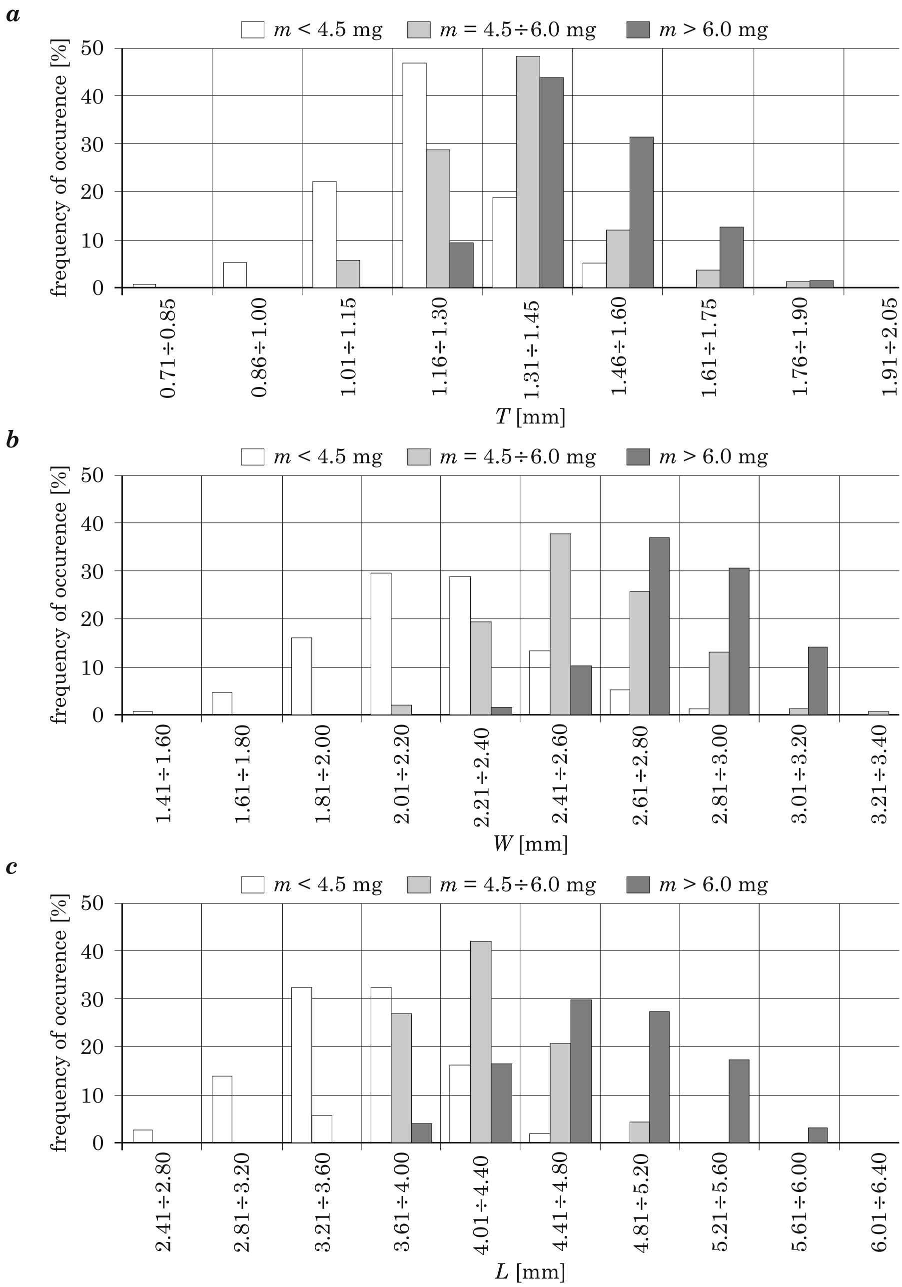

Fig. 2. Distribution of seed fractions based on seed dimensions: *a* – thickness, *b* – width, *c* – length

Conclusions

1. European larch seeds harvested from seed plantations (PN) differed significantly from the material obtained from seed stands (WDN) in all physical parameters and indicators, excluding critical transport velocity. In comparison with WDN seeds, PN seeds were characterized by smaller thickness, width, length, angle of sliding friction, weight, coefficient of sliding friction, arithmetic and geometric mean diameter, specific weight and volume, but higher aspect ratio, sphericity index and density.

2. Seed length and seed weight were the most correlated parameters of European larch seeds (correlation coefficient of approximately 0.8). The relationships among seed weight vs. critical transport velocity, seed thickness and seed width, among seed density vs. critical transport velocity and seed thickness, and among seed dimensions also produced high values of the correlation coefficient (above 0.4).

3. European larch seeds are most effectively separated with the use of mesh screens with round openings (seeds are separated based on width) and/or cylindrical grain graders (seeds are separated based on length). The above devices can separate more than 80% of heavy seeds and up to 7% of light seeds, and they can be effectively used to improve germination efficiency and germination rates of selected seed fractions.

References

ANISZEWSKA M. 2009. *Three-phase extraction of European larch seeds in the local kiln and laboratory*. Annals of Warsaw University of Life Sciences – SGGW. Agriculture, Agricultural and Forest Engineering, 53: 73–78.

ANISZEWSKA M. 2010. *Analysis of opening cones of selected coniferous trees*. Annals of Warsaw University of Life Sciences – SGGW. Agriculture, Agricultural and Forest Engineering, 55: 57–64.

BART-PLANGE A., BARYEH E.A. 2003. *The physical properties of Category B cocoa beans*. Journal of Food Engineering, 60: 219–227.

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. 2010. *Seed characteristics and morphological features of Scots pine (Pinus sylvestris L.) seedlings*. Leśne Prace Badawcze, 71(1): 13–20 (in Polish with English abstract).

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

CASTRO J., REICH P.B., SÁNCHEZ-MIRANDA Á., GUERRERO J.D. 2008. *Evidence that the negative relationship between seed mass and relative growth rate is not physiological but linked to species identity: a within-family analysis of Scots pine*. Tree Physiology, 28: 1077–1082.

CHOSZCZ D., KONOPKA S., ZALEWSKA K. 2010. *Characteristics of physical properties of selected varieties of spelt*. Inżynieria Rolnicza, 4(122): 23–28 (in Polish with English abstract).

CZERNIK Z. 1983a. *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. *Studies of aerodynamical features of seeds of Scotch pine, Norway spruce and European larch*. Sylwan, 9/10: 31–40 (in Polish with English abstract).

CZERNIK Z. 1993. *Studies of Geometrical Properties of Silver Fir Seeds*. Sylwan, 8: 57–64 (in Polish with English abstract).

HEBDA T., MICEK P. 2007. *Geometric features of grain for selected corn varieties*. Inżynieria Rolnicza, 5(93): 187–193 (in Polish with English abstract).

JAWORSKI A. 2011. *Hodowla lasu*. Tom III. *Charakterystyka hodowlana drzew i krzewów leśnych*. Wyd. PWRiL, Warszawa.

JOHNSON M., VANDER WALL S.B., BORCHERT M. 2003. *A comparative analysis of seed and cone characteristics and seed-dispersal strategies of three pines in the subsection Sabinianae*. Plant Ecology, 168: 69–84.

KALINIEWICZ Z. 2013. *Analysis of frictional properties of cereal seeds*. African Journal of Agricultural Research, 8(45): 5611–5621.

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.

KALINIEWICZ Z., MARKOWSKI P., ANDERS A., RAWA T., LISZEWSKI A., 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., POZNAŃSKI A. 2013. *Variability and correlation of selected physical attributes of small-leaved lime (Tilia cordata Mill.) seeds*. Sylwan, 157(1): 39–46 (in Polish with English abstract).

KALINIEWICZ Z., TYLEK P., MARKOWSKI P., ANDERS A., RAWA T., ZADROŻNY M. 2012b. *Determination of shape factors and volume coefficients of seeds from selected coniferous trees*. Technical Sciences, 15(2): 217–228.

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

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., 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.

KUSIŃSKA E., KOBUS Z., NADULSKI R. 2010. *Impact of humidity on physical and geometrical properties of Slavic varieties of rye grains*. Inżynieria Rolnicza, 4(122): 151–156 (in Polish with English abstract).

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.

MATZIRIS D. 1998. *Genetic Variation in Cone and Seed Characteristics in a Clonal Seed Orchard of Aleppo Pine Grown in Greece*. Silvae Genetica, 47(1): 37–41.

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.

MURAT E. 2002. *Szczegółowa hodowla lasu*. Wyd. Oficyna Edytorska „Wydawnictwo Świat", Warszawa.

Nasiennictwo leśnych drzew i krzewów iglastych. 1995. Red. A. ZAŁĘSKI. Wyd. Oficyna Edytorska „Wydawnictwo Świat", Warszawa.

OMOBUWAJO T.O., SANNI L.A., BALAMI Y.A. 2000. *Physical properties of sorry (Hibiscus sabdariffa) seeds*. Journal of Food Engineering, 45: 37–41.

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

PARKER W.C., NOLAND T.L., MORNEAULT A.E. 2006. *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.

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.

QUERO J.L., VILLAR R., MARAÑÓN T., ZAMORA R., 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*. Wyd. Helion, Gliwice.

SABOR J. 1984. *Relation between the weight and the germination capacity of seed of silver fir*. Sylwan, 4: 59–69 (in Polish with English abstract).

SARNOWSKA G., WIĘSIK J. 1998. *Wyłuszczarnia w Czarnej Białostockiej*. Część III. *Czyszczenie i separacja nasion*. Przegląd Techniki Rolniczej i Leśnej, 1: 19–21.

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

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.

SIVACIOĞLU 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.

SIVACIOĞLU A., AYAN S. 2010. *Variation in cone and seed characteristics in clonal seed orchard of Anatolian black pine [Pinus nigra Arnold subsp. pallasiana (Lamb.) Holmboe]*. Journal of Environmental Biology, 31: 119–123.

TURNA I., 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. 1999. *Problems of pneumatic selection of forest tree seeds*. Sylwan, 12: 65-72 (in Polish with English abstract).

TYLEK P. 2004. *Selected physical features and storting criteria for European larch seeds*. Sylwan, 4: 27–33 (in Polish with English abstract).

ZDYBEL A., GAWŁOWSKI S., LASKOWSKI J. 2009. *Influence of moisture content on some physical properties of rye grains*. Acta Agrophysica, 14(1): 243–255 (in Polish with English abstract).