BRIEF REPORT

# An Analysis of the Physical Properties of Seeds of Selected Deciduous Tree Species

**ZDZISŁAW KALINIEWICZ[1], PAWEŁ TYLEK[2], ANDRZEJ ANDERS[1], PIOTR MARKOWSKI[1], TADEUSZ RAWA[1], MAREK OŁDAKOWSKI[1] AND ŁUKASZ WĄSOWSKI[1]**

[1] *Department of Heavy Duty Machines and Research Methodology,*
*University of Warmia and Mazury in Olsztyn, Oczapowskiego 11, 10-719 Olsztyn, Poland*

[2] *Department of Forest Work Mechanization,*
*University of Agriculture in Kraków, Al. 29 Listopada 46, 31-425 Kraków, Poland*

*Corresponding author: Zdzisław Kaliniewicz, Department of Heavy Duty Machines and Research Methodology, University of Warmia and Mazury, Oczapowskiego 11/B112, 10-719 Olsztyn, Poland, ph. 48 89 523 39 34, e-mail: arne@uwm.edu.pl*

**Kaliniewicz, Z., Tylek, P., Anders, A., Markowski, P., Rawa, T., Ołdakowski, M. and Wąsowski, L**. 2016. An analysis of the physical properties of seeds of selected deciduous tree species. *Baltic Forestry* 22(1): 169-174.

*Abstract*

The physical properties of forest tree seeds are an important consideration in seed cleaning and sorting processes. In order to determine variations in and correlations between the pairs of the following parameters: the terminal velocity, thickness, width, length, mass and angle of static friction on steel were measured for seeds of seven deciduous tree species (common beech, copper beech, common hornbeam, small-leaved lime, black locust, mountain ash and grey alder). The results of measurements were processed statistically by correlation analysis and linear regression analysis. Seed mass was most highly correlated and angle of static friction was least 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 relationship between the mass and terminal velocity of small-leaved lime seeds. In view of the above, a pneumatic separator is recommended for separating seeds of the above tree species. A pneumatic separator is also an effective device for separating the seeds of common hornbeam and grey alder. Common beech and mountain ash seeds should be separated with the use of mesh screens, and copper beech and black locust seeds should be separated with the use of a seed grader.

**Key words:** seeds, physical properties, processing, seed quality.

## Introduction

Deciduous trees growing in natural habitats in Poland begin to produce seeds at various age. Seeds can be harvested already from 5-year-old trees growing in open spaces (wild cherry, black locust), whereas dense stands may begin to produce seeds only at the age of 70 years and more (common beech, sessile oak). Most tree species growing in open spaces begin to produce seeds at the age of around 15 years, and trees in dense stands at the age of 20-30 years. In Poland, high seed yields from deciduous trees are noted every 1-2 years, but in some taxa (sessile oak, common beech), the cycle may be prolonged to every 5-8 years (Jaworski 2011).

During processing, seeds are sorted into fractions based on selected physical traits. The seeds of forest trees are generally sorted with the use of simple separating devices, mostly pneumatic separators and mesh screens. Seed separation into fraction improves germination uniformity, which is a particularly important consideration in tree nurseries.

Changes in the physical attributes of tree seeds and the correlations among those parameters are poorly discussed in the literature. The above data is required for designing and modeling seed harvesting, transport, cleaning, sorting, storing, sowing and processing procedures. Significant correlations between the physical traits of same-species seeds could indicate that those seeds have a very similar shape, which has very important implications for the geometry of sorting devices. Weak correlations between physical attributes also carry important information, and they support the determination of the range of variations in the parameters of a sorting device. According to the literature (Khan 2004, Parker et al. 2006, Shankar 2006, Quero et al. 2007, Upadhaya et al. 2007, Castro et al. 2008, Norden et al. 2009), seed mass is one of the main physical properties that affect germination efficiency of seeds of most species. Heavier seeds usually germinate faster and produce healthier seedlings as compared with lighter ones. Seeds are difficult to sort based on their mass. Thus, the correlations between seed mass 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 and the correlations between the physical properties of seeds of selected deciduous trees to increase the efficiency of seed sorting processing.

## Materials and Methods

The analyzed material (Figure 1) comprised the nutlets of common beech (*Fagus silvatica* L.), copper beech (*Fagus silvatica atropurpurea*), common hornbeam (*Carpinus betulus* L.) and small-leaved lime (*Tilia cordata* Mill.), the seeds of black locust (*Robinia pseudoacacia* L.) and mountain ash (*Sorbus aucuparia* L.), and grey alder (*Alnus incana* (L.) Moench) achenes. The seeds of common beech, common hornbeam and small-leaved lime were harvested from the following tree stands listed in the National Register of Forest Reproductive Material:

a) registration No. MP/1/8841/05 (category of seed propagation material – from an identified source, type – tree stand, region of origin – 157, municipality – Rychliki, geographic location – 53.59°N, 19.36°E, forest habitat – fresh forest, age – unknown),

b) registration No. MP/1/40175/05 (category of seed propagation material – from an identified source, type – tree stand, symbol region of origin – 207, municipality – Czarna Białostocka, geographic location – 53.28°N, 23.24°E, forest habitat – fresh forest, age – 114 years),

c) registration No. MP/3/41096/05 (category of seed propagation material – qualified, type – seed plantation, symbol region of origin – 251, municipality – Braniewo, geographic location – 53.49°N, 20.36°E, forest habitat – fresh mixed coniferous forest, age – 15 years).

Seeds of the remaining tree species were supplied by Dendrona of Pęcice and were harvested in the Region of Pomorze Zachodnie.

Seed batches were divided by halving (Załęski 1995). The analyzed batches of nutlets, seeds and achenes (referred to jointly as “seeds” in subsequent parts of this paper) were halved, and one half was randomly selected for successive halving. The above procedure was repeated to produce samples of around 100 seeds each. The resulting seed samples had the following size: common beech – 119, copper beech – 122, common hornbeam – 123, small-leaved lime – 114, black locust – 117, mountain ash – 103 and grey alder – 117. Moisture content was determined with the MAX 50/WH moisture balance (Radwag) on samples collected from the remaining seeds. The moisture content of seeds was as follows: common beech – 11.6 %, copper beech – 11.8 %, common hornbeam – 8.3 %, small-leaved l-ime – 10.5 %, black locust – 8.7 %, mountain ash – 8.8 %, grey alder – 8.1 %.

Terminal velocity of 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 – $Ra$ = 0.48 μm), and seed mass 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), Kaliniewicz and Poznański (2013) and Kaliniewicz et al. (2013). The angle of static friction was determined as the average angle produced by two seed arrangement patterns: with the longitudinal axis parallel and perpendicular to the direction of inclination.

The results were processed with the use of STATISTICA PL v. 10 advanced analytics software package based on general statistical procedures, including correlation analysis and linear regression analysis (Rabiej 2012). Statistical calculations were performed at the significance level of 0.05.

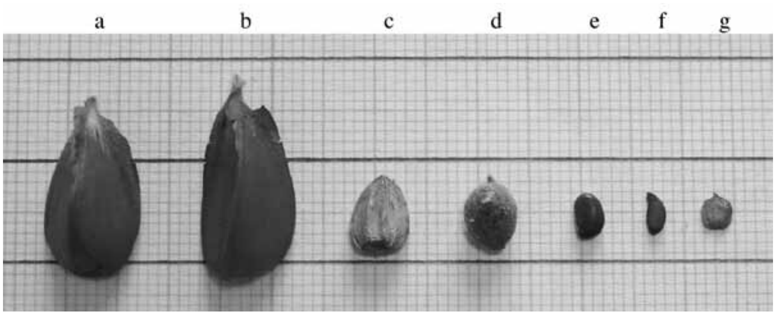


**Figure 1.** Seeds of deciduous trees: a – common beech, b – copper beech, c – common hornbeam, d – small-leaved lime, e – black locust, f – mountain ash, g – grey alder

## Results

The statistical distribution of selected physical attributes of the analyzed seed species is presented in Table 1. Copper beech seeds were characterized by the lowest and small-leaved lime seeds were characterized by the highest variation in parameters. The highest value of the coefficient of variation was reported for seed mass, which ranged from 16.57 to approximately 41.48 %. The second most variable trait in the analyzed seeds, excluding the common beech, was the angle of static friction, which fluctuated in the range of 10.37 to 37.25%. Seed mass was the most diverse trait in the analyzed seed species. The ratio of the average mass of grey alder and copper

**Table 1.** Statistical distribution of the physical properties of selected seed species

| Seed species | Property | Value of trait | | | Standard deviation of trait | Coefficient of trait variability % |
|---|---|---|---|---|---|---|
| | | minimum | maximum | average | | |
| Common beech | *v* (m s$^{-1}$) | 5.78 | 11.28 | 9.34 | 1.14 | 12.23 |
| | *T* (mm) | 5.79 | 10.10 | 7.95 | 0.89 | 11.14 |
| | *W* (mm) | 6.54 | 11.62 | 9.05 | 1.07 | 11.86 |
| | *L* (mm) | 12.11 | 21.20 | 16.39 | 1.64 | 9.99 |
| | *γ* (°) | 17.3 | 32.0 | 23.46 | 2.43 | 10.37 |
| | *m* (mg) | 104.5 | 509.1 | 305.97 | 73.16 | 23.91 |
| Copper beech | *v* (m s$^{-1}$) | 7.43 | 10.73 | 9.02 | 0.84 | 9.34 |
| | *T* (mm) | 6.01 | 9.23 | 7.65 | 0.56 | 7.36 |
| | *W* (mm) | 7.50 | 11.33 | 9.02 | 0.64 | 7.09 |
| | *L* (mm) | 14.37 | 19.97 | 17.45 | 1.33 | 7.65 |
| | *γ* (°) | 16.5 | 31.5 | 25.00 | 2.95 | 11.80 |
| | *m* (mg) | 160.1 | 464.3 | 312.31 | 51.74 | 16.57 |
| Common hornbeam | *v* (m s$^{-1}$) | 6.33 | 10.73 | 9.65 | 0.80 | 8.30 |
| | *T* (mm) | 2.33 | 4.41 | 3.06 | 0.29 | 9.57 |
| | *W* (mm) | 3.20 | 6.86 | 5.22 | 0.63 | 11.98 |
| | *L* (mm) | 3.66 | 9.46 | 7.51 | 0.91 | 12.03 |
| | *γ* (°) | 20.3 | 37.3 | 29.23 | 3.56 | 12.17 |
| | *m* (mg) | 16.5 | 78.1 | 53.27 | 9.19 | 17.25 |
| Small-leaved lime | *v* (m s$^{-1}$) | 4.13 | 11.23 | 8.20 | 1.68 | 20.52 |
| | *T* (mm) | 2.69 | 5.14 | 4.04 | 0.57 | 14.11 |
| | *W* (mm) | 3.18 | 6.00 | 4.57 | 0.52 | 11.47 |
| | *L* (mm) | 3.77 | 6.77 | 5.25 | 0.73 | 13.86 |
| | *γ* (°) | 4.0 | 24.0 | 13.28 | 4.95 | 37.25 |
| | *m* (mg) | 5.8 | 62.2 | 27.69 | 11.48 | 41.48 |
| Black locust | *v* (m s$^{-1}$) | 6.88 | 12.38 | 9.88 | 1.07 | 10.85 |
| | *T* (mm) | 1.25 | 2.22 | 1.75 | 0.22 | 12.41 |
| | *W* (mm) | 2.29 | 4.10 | 3.18 | 0.34 | 10.53 |
| | *L* (mm) | 3.34 | 5.52 | 4.56 | 0.43 | 9.31 |
| | *γ* (°) | 8.5 | 27.0 | 18.13 | 3.68 | 20.29 |
| | *m* (mg) | 6.3 | 28.2 | 18.40 | 4.40 | 23.94 |
| Mountain ash | *v* (m s$^{-1}$) | 3.03 | 6.88 | 5.25 | 0.81 | 15.48 |
| | *T* (mm) | 0.55 | 1.09 | 0.82 | 0.12 | 14.29 |
| | *W* (mm) | 1.28 | 2.18 | 1.73 | 0.20 | 11.67 |
| | *L* (mm) | 2.78 | 4.63 | 3.65 | 0.44 | 11.94 |
| | *γ* (°) | 10.0 | 51.5 | 28.98 | 8.43 | 29.10 |
| | *m* (mg) | 0.4 | 4.6 | 2.49 | 0.82 | 32.93 |
| Grey alder | *v* (m s$^{-1}$) | 0.83 | 3.03 | 1.87 | 0.33 | 17.44 |
| | *T* (mm) | 0.27 | 0.72 | 0.46 | 0.08 | 16.67 |
| | *W* (mm) | 1.58 | 3.39 | 2.42 | 0.36 | 15.05 |
| | *L* (mm) | 1.96 | 3.82 | 2.77 | 0.33 | 11.94 |
| | *γ* (°) | 20.5 | 70.0 | 49.82 | 11.37 | 22.83 |
| | *m* (mg) | 0.2 | 1.0 | 0.49 | 0.17 | 34.17 |

*v* – terminal velocity, *T* – thickness, *W* – width, *L* – length, *γ* – angle of sliding friction, *m* – mass beech seeds was determined at 1:637, and the mass ratio between the heaviest grey alder seeds and the lightest copper beech seeds was determined at 1:160.

A linear correlation analysis (Table 2) of selected physical attributes that can be potentially used in separation processes indicates that seed mass was most correlated with the remaining traits. The highest values of the correlation coefficient were noted in a comparison of seed mass with terminal velocity (common beech – 0.499, small-leaved lime – 0.846), seed thickness (common beech – 0.655), seed width (mountain ash – 0.705) and seed length (copper beech – 0.604, black locust – 0.779). The mass of grey alder seeds was most correlated with seed thickness and terminal velocity (0.534). The angle of static friction was least correlated with the remaining parameters.

The above observations were confirmed by the results of linear regression analysis (Table 3), where mathematical dependencies between seed mass and the angle of static friction with a coefficient of determination higher than 0.1 were not derived for any seed species. The equation with the highest coefficient of determination was derived for the correlation between the mass and terminal velocity of small-leaved lime seeds (0.716). High values of the coefficient of determination (higher than 0.4) were also noted in correlations between seed mass and:

- terminal velocity of mountain ash seeds,
- seed thickness of common beech and black locust seeds,
- seed width of small-leaved lime, black locust and mountain ash seeds,
- seed length of black locust seeds.

**Table 2.** Values of Pearson's correlation coefficients between selected seed properties

| Seed species | Property | *T* | *W* | *L* | *γ* | *m* |
|---|---|---|---|---|---|---|
| Common beech | *v* | 0.119 | **0.202** | -0.059 | **0.307** | **0.541** |
| | *T* | 1 | **0.591** | **0.193** | 0.034 | **0.655** |
| | *W* | | 1 | 0.122 | 0.062 | **0.583** |
| | *L* | | | 1 | 0.105 | **0.405** |
| | *γ* | | | | 1 | **0.208** |
| Copper beech | *v* | 0.090 | 0.071 | 0.141 | **0.207** | **0.386** |
| | *T* | 1 | **0.213** | **0.190** | **-0.285** | **0.551** |
| | *W* | | 1 | -0.040 | -0.016 | **0.400** |
| | *L* | | | 1 | **-0.252** | **0.604** |
| | *γ* | | | | 1 | **-0.213** |
| Common hornbeam | *v* | -0.001 | **0.219** | -0.014 | -0.002 | **0.499** |
| | *T* | 1 | -0.017 | **0.402** | **-0.228** | **0.458** |
| | *W* | | 1 | -0.068 | -0.165 | **0.308** |
| | *L* | | | 1 | -0.149 | **0.403** |
| | *γ* | | | | 1 | **-0.231** |
| Small-leaved lime | *v* | **0.244** | **0.392** | **0.335** | -0.095 | **0.846** |
| | *T* | 1 | **0.798** | **0.586** | **0.349** | **0.513** |
| | *W* | | 1 | **0.675** | **0.239** | **0.663** |
| | *L* | | | 1 | **0.284** | **0.555** |
| | *γ* | | | | 1 | 0.108 |
| Black locust | *v* | **0.658** | **0.264** | **0.282** | -0.078 | **0.556** |
| | *T* | 1 | **0.341** | **0.376** | **-0.308** | **0.764** |
| | *W* | | 1 | **0.603** | 0.139 | **0.680** |
| | *L* | | | 1 | 0.147 | **0.779** |
| | *γ* | | | | 1 | -0.052 |
| Mountain ash | *v* | **0.630** | **0.428** | 0.152 | -0.172 | **0.684** |
| | *T* | 1 | **0.507** | 0.051 | **-0.215** | **0.622** |
| | *W* | | 1 | **0.395** | 0.011 | **0.705** |
| | *L* | | | 1 | -0.039 | **0.535** |
| | *γ* | | | | 1 | **-0.216** |
| Grey alder | *v* | **0.534** | -0.102 | 0.013 | 0.067 | **0.433** |
| | *T* | 1 | -0.127 | 0.074 | -0.039 | **0.301** |
| | *W* | | 1 | **0.641** | **-0.199** | **0.358** |
| | *L* | | | 1 | -0.082 | **0.367** |
| | *γ* | | | | 1 | -0.088 |

*v* – terminal velocity, *T* – thickness, *W* – width, *L* – length, *γ* – angle of sliding friction, *m* – mass; values in bold indicate that the correlation is significant at $p = 0.05$

**Table 3.** Correlations between seed mass and each of physical properties of selected seed species

| Seed species | Equation | Coefficient of determination $R^2$ | Standard error of estimate |
|---|---|---|---|
| Common beech | $m = 34.643v - 17.698$ | 0.293 | 61.776 |
| | $m = 54.075T - 123.898$ | 0.429 | 55.527 |
| | $m = 39.754W - 53.951$ | 0.341 | 59.667 |
| | $m = 18.070L - 9.826$ | 0.163 | 67.192 |
| Copper beech | $m = 23.744v + 98.228$ | 0.149 | 47.922 |
| | $m = 50.588T - 74.589$ | 0.303 | 43.373 |
| | $m = 32.401W + 20.172$ | 0.160 | 47.616 |
| | $m = 23.409L - 96.263$ | 0.365 | 41.418 |
| Common hornbeam | $m = 5.727v + 1.980$ | 0.249 | 7.997 |
| | $m = 14.390T + 9.267$ | 0.210 | 8.204 |
| | $m = 4.082L + 22.615$ | 0.163 | 8.445 |
| Small-leaved lime | $m = 5.774v - 19.669$ | 0.716 | 6.152 |
| | $m = 10.349T - 14.096$ | 0.263 | 9.900 |
| | $m = 14.534W - 38.688$ | 0.439 | 8.639 |
| | $m = 8.761L - 18.302$ | 0.308 | 9.596 |
| Black locust | $m = 2.284v - 4.173$ | 0.309 | 3.677 |
| | $m = 15.469T - 8.742$ | 0.585 | 2.850 |
| | $m = 8.927W - 10.025$ | 0.462 | 3.245 |
| | $m = 8.087L - 18.487$ | 0.608 | 2.771 |
| Mountain ash | $m = 0.691v - 1.133$ | 0.467 | 0.603 |
| | $m = 4.356T - 1.079$ | 0.386 | 0.647 |
| | $m = 2.869W - 2.468$ | 0.497 | 0.586 |
| | $m = 1.009L - 1.185$ | 0.286 | 0.697 |
| Grey alder | $m = 0.224v + 0.075$ | 0.187 | 0.153 |
| | $m = 0.166W + 0.092$ | 0.128 | 0.158 |
| | $m = 0.187L - 0.025$ | 0.135 | 0.157 |

$v$ – terminal velocity (m $s^{-1}$), $T$ – thickness (mm), $W$ – width (mm), $L$ – length (mm), $m$ – mass (mg)

## Discussion

Seeds harvested from various deciduous tree species and characterized by different dimensions and mass were analyzed in this study. The heaviest common beech seeds were more than 2500-fold heavier than the lightest grey alder seeds. Common beech seeds had similar dimensions to those given by Bodył and Sułkowska (2007), but they were considerably heavier. The above seeds were characterized by lower terminal velocity than that noted by Tylek (2011). The average mass of common hornbeam seeds was higher than that described by Aguinagalde et al. (2005). The evaluated seeds of small-leaved lime were similar in width and length to seeds harvested from a seed plantation in north-eastern Poland (region of origin – 106) by Ludwikowska et al. (2011), but they were lighter than the samples investigated by Aguinagalde et al. (2005). The average mass of black locust seeds was lower in comparison with Greek seeds analyzed by Dini-Papanastasi et al. (2012), but higher in comparison with Turkish seeds (Basbag et al. 2010). The range of variations in the dimensions and mass of mountain ash seeds was similar to that noted by Paulsen and Högstedt (2002) and Bednorz et al. (2006), but the average values observed in this study were lower than those given by the cited authors. The average mass of grey alder seeds was lower than that observed by Milbau et al. (2009). Seed mass was the most variable physical trait in all analyzed species. Seed mass is highly correlated with seed dimensions (Table 2), therefore, every change in seed thickness, width or length leads to changes in seed mass.

The angle of static friction was least correlated with the remaining attributes. The observations made in this study and the results reported by Tylek (2006) for common beech seeds suggest that the frictional properties of seeds of deciduous trees may not be regarded as major separating properties, but only as auxiliary attributes in the separation process. Seed mass was most highly correlated with the remaining traits. Similar values of the correlation coefficient between seed mass and each of seed dimensions were reported by Sivacioğlu (2010) in Scots pine, and Sivacioğlu and Ayan (2010) in black pine. According to many authors (Khan 2004, Parker et al. 2006, Shankar 2006, Quero et al. 2007, Upadhaya et al. 2007, Castro et al. 2008, Norden et al. 2009, Kaliniewicz et al. 2012, 2013), seed mass influences germination efficiency, but heavy seeds do not always germinate faster than light seeds. Heavier seeds are generally more likely to germinate and produce healthy seedlings because plump seeds accumulate more storage reserves that are essential for seedling emergence.

The observed correlations between seed mass and the remaining attributes are characterized by relatively high determination coefficients for biological material. The noted results indicate that seeds of common hornbeam, small-leaved lime and grey alder would be sorted most effectively in a pneumatic separator (terminal velocity), common beech seeds – in mesh screens with longitudinal openings (thickness), mountain ash seeds – in mesh screens with round openings (width), and the seeds of copper beech and black locus – in a grader (length). If the preferred sorting device is not available, a pneumatic separator could also be used to sort mountain ash seeds, a mesh screen with longitudinal openings to separate copper beech, common hornbeam and black locust seeds, and a mesh screen with round openings – to sort seeds of the common beech and small-leaved lime.

## Acknowledgments

*This research study was financed by the Department of Heavy Duty Machines and Research Methodology, Faculty of Technical Sciences of the University of Warmia and Mazury in Olsztyn.*

## References

**Aguinagalde, I., Hampe, A., Mohanty, A., Martin, J.P., Duminil, J. and Petit, R.J.** 2005. Effects of life-history traits and species distribution on genetic structure at maternally inherited markers in European trees and shrubs. *Journal of Biogeography* 32: 329-339.

**Basbag, M., Aydin, A. and Ayzit, D.** 2010. The Effects of Different Temperatures and Durations on the Dormancy Breaking of Black Locust (*Robinia pseudoacacia* L.) and Honey Locust (*Gleditsia triacanthos* L.) Seeds. *Notulae Scientia Biologicae* 2(4): 125-128.

**Bednorz, L., Walkowiak, R., Maciejewska-Rutkowska, I. and Moliński, K.** 2006. Seed variability of the Polish species of the genus *Sorbus* (Rosaceae). *Dendrobiology* 55: 3-9.

**Bodył, M. and Sułkowska, M.**, 2007. Ocena zróżnicowania nasion buka zwyczajnego (*Fagus sylvatica* L.) w Polsce w latach 1992−2004 [Estimation of European beech (*Fagus sylvatica* L.) seed differentiation in Poland in the years 1992-2004]. *Sylwan* 9: 12-21 (in Polish with English abstract).

**Castro, J., Reich, P.B., Sánchez-Miranda, Á. and 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.

**Dini-Papanastasi, O., Kostopoulou, P. and Radoglou, K.** 2012. Effect of seed origin, growing medium and mini-plug density on early growth and quality of black locust (*Robinia pseudoacacia* [L.]) seedling. *Journal of Forest Science* 1: 8-20.

**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., 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.** 2012. Correlations between the germination capacity and selected attributes of European larch seeds (*Larix decidua* Mill.). *Technical Sciences* 15(2): 229-242.

**Kaliniewicz, Z. and Poznański, A.** 2013. Zmienności i wzajemna korelacja wybranych cech fizycznych nasion lipy drobnolistnej (*Tilia cordata* Mill.) [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., Jóźwiak, K. and Fura, S.** 2013. Correlations between the germination capacity and selected physical properties of Scots pine (*Pinus sylvestris* L.) seeds. *Baltic Forestry* 19(2): 201-211.

**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.

**Ludwikowska, A., Kowalkowski, W. and Tarasiuk, S.** 2011. Wzrost szczepów lipy drobnolistnej (*Tilia cordata* Mill.) na plantacji nasiennej w Nadleśnictwie Susz [The growth of small-leaved lime (*Tilia cordata* Mill.) clones in a seed orchard in the Susz Forest District]. *Forest Research Papers* 72(2): 121-130 (in Polish with English abstract).

**Milbau, A., Graae, B.J., Shevtsova, A. and Nijs, I.** 2009. Effects of a warmer climate on seed germination in the subarctic. *Annals of Botany* 104: 287-296.

**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.

**Parker, W.C., Noland, T.L. and 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.

**Paulsen, T.R. and Högstedt, G.** 2002. Passage through bird guts increases germination rate and seedling growth in *Sorbus aucuparia*. *Functional Ecology* 16: 608-616.

**Rabiej, M.** 2012. Statystyka z programem Statistica [Statisctics with Statistica package]. Ed. Helion, Gliwice, ISBN 978-83-246-4110-9 (in Polish).

**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. and 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.

**Tylek, P.** 2006. Tarcie i sprężystość jako cechy rozdzielcze bukwi [Friction and elasticity as separation properties of beech nuts]. *Sylwan* 5: 51-58 (in Polish with English abstract).

**Tylek, P.** 2011. Analiza cech aerodynamicznych našion jodły pospolitej i buka zwyczajnego [Analysis of aerodynamic properties of common fir and common beech]. *Inżynieria Rolnicza* 6(131): 247-253 (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.

**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).

Received 29 June 2014
Accepted 25 January 2016