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SELECTED PHYSICAL PARAMETERS OF COMMON HORNBEAM (*CARPINUS BETULUS* L.) NUTS

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Abstract

Selected physical parameters of common hornbeam nuts were determined in five batches of nuts harvested from seed tree stands in northern Poland. The results were used to calculate the arithmetic and geometric mean diameters, aspect ratio, sphericity index, volume and density of each nut. The above parameters were compared by analysis of variance, correlation analysis and linear regression analysis. Habitat conditions had a greater influence on nut plumpness than the age of the tree stand. Nut width was highly correlated with nut mass, and the above observation can be used in the process of separating nuts into mass categories. When two mesh screens with 5 mm and 6 mm openings are used, nuts will be separated into a fine-sized fraction containing 71.4% of nuts with reduced plumpness, 24.1% of moderately plump nuts and 1.8% of plump nuts, and a coarse-sized fraction containing 2.0% of nuts with reduced plumpness, 43.6% of moderately plump nuts and 54.4% of plump nuts.

Symbols

D_a – arithmetic mean diameter of a nut, mm,
D_g – geometric mean diameter of a nut, mm,
k – volumetric coefficient of proportionality,
m – nut mass, mg,
R – aspect ratio, %,
SD – standard deviation of trait,
T, W, L – nut thickness, width and length, mm,
v – terminal velocity of a nut, m s^{-1},
V – nut volume, mm^3,
x – average value of trait,
γ – angle of static friction on steel, averaged for three nut positions on a steel friction plate, °

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γ_1, γ_2, γ_3 – angle of static friction on a steel friction plate when the long axis of the nut is parallel to the direction of movement with the hilum down and up, and when the long axis is perpendicular to the direction of movement, °,
ρ – nut density, g cm^{-3},
Φ – sphericity index, %.

Introduction

The common hornbeam (*Carpinus betulus* L.) is a tree with a broad and irregular crown, and it grows to a height of 10–25 m. Its geographic range covers Central and Southern Europe, Caucasus, northern Turkey and Iran. It is a typical representative of lowland and highland tree species. The common hornbeam is rarely encountered at altitudes higher than 1000 m.a.s.l. It thrives on loamy, sandy and loamy, deep, fresh and fertile soils (SUSZKA et al. 2000, MURAT 2002, JAWORSKI 2011). It is a common admixture in stands of pines, oaks and beeches, and oak-linden-hornbeam forests are the optimal habitat for the analyzed species (MURAT 2002, BORATYŃSKI et al. 2007).

The common hornbeam is a monoecious species which produces individual male and female flowers on the same tree. It begins to produce fruit at the age of approximately 30 years, and abundant yields are reported every 2–3 years. Trees produce fruit even every year in locations with adequate sun exposure (SUSZKA et al. 2000, WESOŁOWSKI et al. 2015). Flowers appear in April or May, and inflorescences with a length of 5–15 cm mature between August and November, mostly in October. The fruit of the common hornbeam are nuts which are initially light green in color, but grow darker in successive stages of maturation to turn olive green and brown in fall (Fig. 1). Each nut is shielded by a 3-segmented seed coat which acts as a wing during dispersal. Mature nuts fall to the ground between fall and spring (SUSZKA et al. 2000, MURAT 2002, BORATYŃSKI et al. 2007, DRAGOMIR, SZEKELY 2011, JAWORSKI 2011).

Hornbeam nuts are harvested when maturing inflorescences turn olive green or brown. Nuts are harvested manually, they can be shaken off trees or collected from twigs that are cropped into sheets or nets spread under trees. The collected inflorescences are lightly dried, and nuts are mechanically separated from wings. Small amounts of seeds can be placed in a hard-wearing fabric bag and threshed by hitting with a flail or by stomping on top of the bag. Seed coats and crushed nut fragments are removed on a mesh screen, in a winnowing machine or a pneumatic sieve (SUSZKA et al. 2000, MURAT 2002).

Hornbeam nuts belong to the category of orthodox seeds which can withstand significant dehydration without losing their viability. Partially dried (8–10%) orthodox seeds can be stored at low temperatures (below 0°C) for many years. In hornbeam nuts, pre-sowing treatment is performed in deep

Fig. 1. View of common hornbeam nuts

dormancy, and it involves warm and cold stratification over a period of 18–20 weeks (SUSZKA et al. 2000, MURAT 2002, CZAPRACKI, HOLUBOWICZ 2010, ZHU et al. 2014).

According to the literature (KHAN 2004, PARKER et al. 2006, SHANKAR 2006, QUERO et al. 2007, BURACZYK 2010), seed mass is one of the key parameters that determine germination efficiency in most species. Plump seeds contain more reserve materials which are required for sprouting and contribute to the development of healthy germs. Despite the above, seeds are difficult to sort based only on their mass. Vibratory separators or pneumatic vibratory separators can be used, but in most processes, seeds are separated based on differences in their density. The separation process is effective when seeds have similar density but differ in size or when seeds have similar size but differ in density (GROCHOWICZ 1994). The separation process may be unsuccessful if seeds differ in both size and density, which is often the case in seed material. Thus, correlations between the physical parameters of seeds need to be identified to increase the efficiency of separation and support the selection of optimal parameters in separation equipment.

The objective of this study was to determine the variations in and correlations between the basic physical parameters of common hornbeam nuts so as to improve the efficiency of seed separation processes.

Materials and Methods

The experimental material comprised five batches of common hornbeam nuts supplied by a seed extraction plant in Jedwabno in 2012. Three batches were harvested from variously aged seed tree stands in one forest region, and two batches were obtained from similarly aged seed tree stands in the regions of Mazury and Podlasie in northern Poland. The analyzed batches were harvested from the following tree stands:

a) registration No. MP/1/45603/06, category of seed propagation material – from an identified source, region of origin – 205, municipality – Szczytno, geographic location – 53.32°N, 20.57°E, forest habitat – fresh forest, age – 77 years (symbol: CH-1a),

b) registration No. MP/1/44582/06, category of seed propagation material – from an identified source, region of origin – 206, municipality – Świętajno, geographic location – 53.35°N, 21.23°E, forest habitat – fresh forest, age – 71 years (symbol: CH-1b),

c) registration No. MP/1/9366/05, category of seed propagation material – from an identified source, region of origin – 251, municipality – Bartoszyce, geographic location – 54.12°N, 20.42°E, forest habitat – fresh forest, age – 74 years (symbol: CH-1c),

d) registration No. MP/1/42001/05, category of seed propagation material – from an identified source (removed from the list), region of origin – 251, municipality – Kolno, geographic location – 53.56°N, 21.03°E, forest habitat – fresh forest, age – 85 years (symbol: CH-2),

e) registration No. MP/1/43925/05, category of seed propagation material – from an identified source, region of origin – 251, municipality – Biskupiec, geographic location – 53.57°N, 20.53°E, forest habitat – fresh forest, age – 90 years (symbol: CH-3).

Analytical samples (initial samples had the weight of 1 kg) from every batch of nuts were divided by halving (*Nasiennictwo leśnych drzew*... 1995). Initial samples were halved, and one half was randomly selected for successive halving. The above procedure was repeated to produce samples of around 100 nuts each. The analyzed nut samples had the following size: CH-1a–109, CH-1b–118, CH-1c–111, CH-2–112, CH-3–122. The remaining nuts were sampled to determine their moisture content in the Radwag MAX 50/WH drying oven with a weighing scale. The analyzed nuts were characterized by similar moisture content in the range of 8.4% to 8.9%.

Terminal velocity of nuts 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 = 0.45 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) and KALINIEWICZ and POZNAŃSKI (2013). The angle of static friction was measured in three positions: with the longitudinal axis parallel to the direction of movement with the hilum down (index 1) and the hilum up (index 2), and with the longitudinal axis perpendicular to the direction of movement (index 3).

The physical parameters of nuts were used to determine their arithmetic and geometric mean diameters, aspect ratio and sphericity index (MOHSENIN 1986):

$$D_a = \frac{T + W + L}{3} \tag{1}$$

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

$$R = \frac{W}{L} \times 100 \tag{3}$$

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

A 25 cm^3 liquid pycnometer with a thermometer and a capillary tube was used to determine volume V_p of all nuts in a given sample. The volume and density of each nut was calculated based on the below formula:

$$V = k \cdot T \cdot W \cdot L \tag{5}$$

$$\rho = \frac{m}{V} = \frac{m}{k \cdot T \cdot W \cdot L} \tag{6}$$

where:

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

Nuts were divided into three plumpness categories based on their mass: seeds with reduced plumpness ($m < x$–SD), moderately plump seeds (x–SD $\leq m \leq x$+SD) and plump seeds ($m > x$+SD). The results were rounded off to the next multiple of 5.

The results were processed in the Statistica v. 10 application with the use of popular statistical procedures such as one-way ANOVA, correlation analysis and linear regression analysis (RABIEJ 2012). The results were regarded as significant at P-value of 0.05.

Results

The physical parameters of common hornbeam nuts are presented in Table 1. The volume and density of nuts were determined with the use of formulas (5) and (6) where the volumetric coefficient of proportionally was $k = 0.475$. The above value of k implies that a nut fills a rectangular cuboid, characterized by three basic parameters T, W and L, in 47.5%.

Table 1

Variations in the physical parameters of hornbeam nuts with an indication of significant differences

Property/ indicator	Nut batch				
	CH-1a x±SD	CH-1b x±SD	CH-1c x±SD	CH-2 x±SD	CH-3 x±SD
v [m s^{-1}]	10.00 ± 0.88^{a}	10.07 ± 1.11^{a}	9.63 ± 0.90^{bB}	10.01 ± 1.15^{A}	9.82 ± 0.93^{AB}
T [mm]	2.86 ± 0.27^{a}	2.85 ± 0.28^{a}	2.88 ± 0.29^{aA}	2.86 ± 0.29^{A}	2.85 ± 0.27^{A}
W [mm]	5.20 ± 0.48^{b}	5.92 ± 0.52^{a}	5.80 ± 0.54^{aA}	5.80 ± 0.58^{A}	5.87 ± 0.53^{A}
L [mm]	6.15 ± 0.71^{b}	6.67 ± 0.64^{a}	6.70 ± 0.61^{aA}	6.66 ± 0.59^{A}	6.75 ± 0.65^{A}
γ_1 [°]	23.99 ± 3.11^{a}	24.36 ± 2.88^{a}	24.26 ± 3.62^{aAB}	24.93 ± 2.43^{A}	23.70 ± 2.26^{B}
γ_2 [°]	23.96 ± 3.03^{a}	24.46 ± 2.65^{a}	24.02 ± 3.29^{aB}	25.05 ± 2.47^{A}	23.97 ± 2.20^{B}
γ_3 [°]	24.57 ± 3.15^{a}	24.36 ± 2.84^{a}	24.34 ± 2.94^{aA}	24.46 ± 2.19^{A}	23.54 ± 2.38^{B}
m [mg]	43.06 ± 8.10^{b}	49.97 ± 11.80^{a}	48.91 ± 10.48^{aA}	46.13 ± 11.01^{A}	47.57 ± 9.54^{A}
D_a [mm]	4.78 ± 0.38^{b}	5.15 ± 0.37^{a}	5.13 ± 0.38^{aA}	5.11 ± 0.40^{A}	5.16 ± 0.36^{A}
D_g [mm]	4.50 ± 0.34^{b}	4.82 ± 0.33^{a}	4.81 ± 0.35^{aA}	4.79 ± 0.37^{A}	4.82 ± 0.33^{A}
R [%]	85.20 ± 9.25^{b}	89.23 ± 8.54^{a}	86.94 ± 8.04^{abA}	87.41 ± 8.30^{A}	87.64 ± 9.49^{A}
Φ [%]	73.48 ± 4.69^{a}	72.56 ± 4.83^{ab}	71.96 ± 4.04^{bA}	72.13 ± 3.86^{A}	71.79 ± 4.69^{A}
V [mm^3]	43.87 ± 9.79^{b}	53.95 ± 11.39^{a}	53.72 ± 12.04^{aA}	53.22 ± 12.40^{A}	53.97 ± 10.79^{A}
ρ [g cm^{-3}]	0.99 ± 0.10^{a}	0.93 ± 0.13^{b}	0.92 ± 0.13^{bA}	0.88 ± 0.13^{B}	0.89 ± 0.15^{AB}

a, b – different letters indicate statistically significant differences in the value of a given parameter (indicator) between nuts harvested from similarly aged tree stands,
A, B – different letters indicate statistically significant differences in the value of a given parameter (indicator) between nuts harvested from the same forest region.

The errors in the estimated mean physical parameters of nuts did not exceed:
- for terminal velocity of a nut – 0.3 m s^{-1},
- for nut thickness – 0.1 mm,
- for nut width and length – 0.2 mm,
- for the angle of static friction – 0.7°,
- for nut mass – 2.2 mg.

The highest average terminal velocity was noted in batch CH-1b. Nuts from that batch were also characterized by the highest mean width, mass, geometric mean diameter and aspect ratio. In general, the lowest mean values of the measured parameters were observed in batch CH-1a in respect of the width, length, angle of static friction of nuts placed on a steel surface with the hilum up, mass, arithmetic and geometric mean diameters, aspect ratio and volume. Nuts from batch CH-1a were characterized by the highest mean values of the angle of static friction of nuts placed on a steel surface perpendicular to the direction of movement, sphericity index and density. Nuts harvested from similarly aged tree stands differed in all parameters and indicators, excluding thickness. It should be noted that none of the analyzed parameters was responsible for significant differences between the three examined batches. Nuts harvested from the same forest region differed locally only in their terminal velocity, angle of static friction and density. No significant differences were noted in the remaining parameters and indicators. Smaller differences in the measured parameters were observed between nuts harvested from the same forest region than between nuts harvested from different forest regions, which suggests that the characteristic attributes of common hornbeam nuts are influenced by the local climate.

The smallest angle of static friction was noted in CH-3 nuts positioned on a steel surface with the longitudinal axis perpendicular to the direction of movement, and the largest angle of static friction was observed in CH-2 nuts positioned on a steel surface with the longitudinal axis parallel to the direction of movement with the hilum down (Tab. 1). Despite statistically significant local differences in the angle of static friction between batches, the difference between the largest and smallest mean angle was estimated at only 6% (1.5°). An additional analysis of variance (the results are not given in Table 1) revealed an absence of significant differences between the angle of static friction of differently positioned nuts. For this reason, the mean angle of static friction from three positions was used in further analyses.

Despite the presence of statistically significant local differences, none of the analyzed batches differed considerably from the remaining batches, and the five analyzed batches of common hornbeam nuts were regarded as homogeneous. An analysis of linear correlations between the physical parameters of nuts (Tab. 2) revealed that nearly all evaluated traits were significantly correlated at 0.05. The only exceptions were terminal velocity, nut thickness and width. The correlations between the mass and basic dimensions of nuts, between nut density vs. terminal velocity and nut thickness, and between nut length and nut width were deemed as practically significant (coefficients of correlation higher than 0.4). The highest value of the correlation coefficient (0.727) was observed in a comparison of nut mass and nut width.

Table 2

Coefficients of linear correlation between selected physical parameters of hornbeam nuts

Property	T	W	L	γ	m	ρ
υ	0.044	0.061	**-0.130**	**-0.275**	**0.332**	**0.501**
T	1	**0.262**	**0.289**	**-0.150**	**0.411**	**-0.420**
W	–	1	**0.528**	**-0.250**	**0.727**	**-0.165**
L	–	–	1	**-0.090**	**0.617**	**-0.356**
γ	–	–	–	1	**-0.320**	**-0.149**
m	–	–	–	–	1	**0.243**

Values in bold represent statistically significant correlations.

Regression equations where the coefficient of determination is higher than 0.2 are presented in Table 3. This condition was fulfilled by the relationships between the terminal velocity and density of nuts, between nut width and nut length, between nut length and nut mass, and between nut mass and nut width. The equation describing the relationship between nut width and nut mass was characterized by the highest value of the determination coefficient (0.529), and the highest percentage of explained variation. The above indicates that common hornbeam nuts should be divided into mass categories with the use of mesh screens with round openings.

Table 3

Regression equations for the physical parameters of hornbeam nuts

Equation	Coefficient of determination R^2	Standard error of the estimate
$\upsilon = 3.792\ \rho + 6.406$	0.251	0.875
$W = 0.461\ L + 2.687$	0.278	0.502
$W = 0.041\ m + 3.803$	0.529	0.405
$L = 0.603\ W + 3.137$	0.278	0.574
$L = 0.040\ m + 4.724$	0.381	0.531
$m = 12.968\ W - 27.098$	0.529	7.226
$m = 9.624\ L - 16.271$	0.381	8.283
$\rho = 0.066\ \upsilon + 0.266$	0.251	0.116

The average mass of common hornbeam nuts was determined at 47.18 ± 10.52 mg. Separation boundaries were rounded off to produce three nut plumpness categories: nuts with reduced plumpness (m<40 mg), moderately plump nuts (m = 40÷55 mg) and plump nuts (m>55 mg). The analyzed material contained 27.1% of nuts with reduced plumpness, 50.7% of moderately plump nuts and 22.2% of plump nuts. Figure 2 presents the distribution of nut width across three plumpness categories. Nuts representing all three plumpness categories are found in nearly every size fraction, excluding the two smallest (W≤4.5 mm) and the two largest (W>6.5 mm) fractions. When two mesh screens with 5 mm and 6 mm openings are used, nuts will be separated into three size fractions. The smallest fraction will contain approximately 28% of nuts with reduced plumpness, 5% of moderately plump nuts and only 1% of plump nuts. The material passed through the top mesh sieve will contain approximately 3% of nuts with reduced plumpness, 29% of moderately plump nuts and 84% plump nuts.

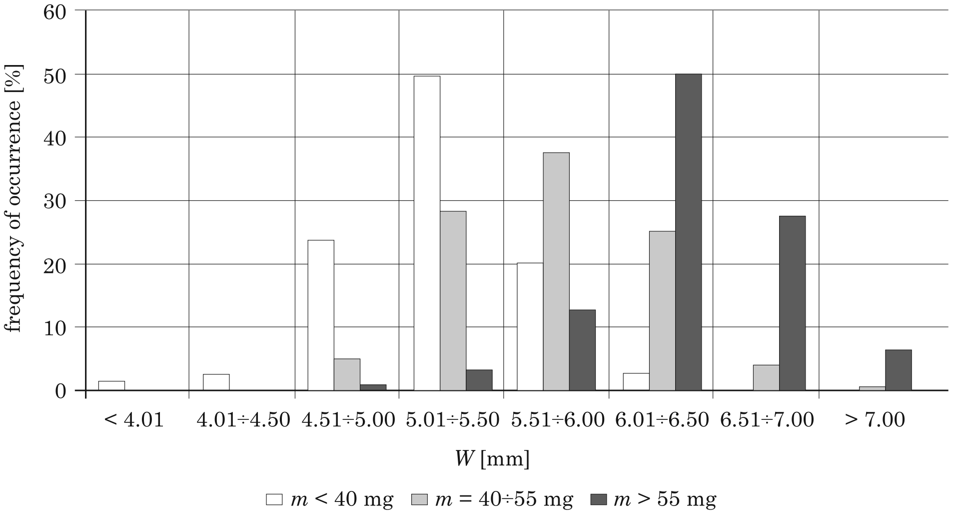

Fig. 2. Distribution of nut width across three mass categories

The separated size fractions will contain:

– fine-sized fraction ($W \leq 5$ mm) – 74.1% of nuts with reduced plumpness, 24.1% of moderately plump nuts and 1.8% of plump nuts,

– medium-sized fraction (W = 5–6 mm) – 33.9% of nuts with reduced plumpness, 59.9% of moderately plump nuts and 6.2% of plump nuts,

– coarse-sized fraction (W>6 mm) – 2.0% of nuts with reduced plumpness, 43.6% of moderately plump nuts and 54.4% of plump nuts.

Discussion

According to FRĄCZEK (1999) and HORABIK (2001), the frictional properties of seeds are determined by various factors, including seed orientation relative to the direction of movement. The above hypothesis was not confirmed by the results of our study where the position of common hornbeam nuts relative to the steel friction plate was not significantly correlated with the resulting angle of sliding friction. The above could be attributed to the fact that unlike most seeds, hornbeam nuts have a ribbed rather than a smooth surface. Due to relatively small contact area between nuts and the friction plate, the components of the friction force (deformation, adhesion and cohesion) do not undergo significant change, therefore, the angle of static friction remains similar when nuts are positioned differently on the steel surface. Our results indicate that when the angle of static friction is used as a separation trait, the position of common hornbeam nuts on the friction plate does not have to be precisely adjusted.

When the angle of static friction of hornbeam nutlets (approximately 24°) was converted into the coefficient of friction, our results were comparable with the values reported by BART-PLANGE and BARYEH (2003) in cocoa beans, by ALTUNTAŞ et al. (2005) in fenugreek seeds, by ÇALIŞIR et al. (2005) in Turkish okra seeds, and by MARKOWSKI et al. (2013) in wheat grain.

The mean terminal velocity of hornbeam nuts, which was determined in the range of 9.63 m s^{-1} to 10.07 m s^{-1}, was similar to that reported in filled beech nuts (TYLEK 2011). In terms of thickness, hornbeam nuts were similar to wheat seeds (GEODECKI, GRUNDAS 2003, KALKAN, KARA 2011, MARKOWSKI et al. 2013) and roselle seeds (SÁNCHEZ-MENDOZA et al. 2008), and in terms of width – to fir seeds (CZERNIK 1993), cowpeas (KABAS et al. 2007) and yellow lupine seeds (SADOWSKA, ŻABIŃSKI 2011). When both width and thickness were taken into account, hornbeam nuts were similar to lentils (RYBIŃSKI et al. 2009), and when width was combined with length, the analyzed nuts were similar to soybeans (DAVIES, EL-OKENE 2009). The sphericity index of hornbeam nuts was similar to that of ackee apple seeds (OMOBUWAJO et al. 2000). There are no published data on the range of variations in the physical parameters of hornbeam nuts. The only cited parameter is nut mass which, according to SUSZKA et al. (2000) and AGUINAGALDE et al. (2005), should range from 35 mg to 45 mg. In this study, nuts in four out of the five analyzed batches were heavier than 45 mg. The proportion of plump nuts in the evaluated material indicates that 2012 was a favorable year for the generative reproduction of hornbeams.

For a biological material, the regression equations presented in Table 3 effectively explain the relationships between the analyzed traits, and they can be used to model and perform separation processes.

Seed mass is one of the key parameters determining germination efficiency in most seed species, but the heaviest seeds are not always the first to sprout (KHAN 2004, PARKER et al. 2006, SHANKAR 2006, QUERO et al. 2007, UPADHAYA et al. 2007, NORDEN et al. 2009, BURACZYK 2010). Seeds can be separated into mass fractions to promote even germination, which is a very important production factor in tree nurseries. However, it is very difficult to separate seeds based on their mass only. For this reason, parameters that are significantly correlated with mass are identified and used in seed cleaning and separation process. In this study, the mass of common hornbeam nuts was most highly correlated with nut width. Our results indicate that hornbeam nuts should be separated with the use of mesh screens with round openings. The basic dimensions of hornbeam nuts were negatively correlated with nut density, which suggests that smaller nuts will germinate earlier than plump nuts. Further research is needed to verify this hypothesis.

Conclusions

1. An analysis of the physical parameters of common hornbeam nuts revealed greater differences between batches of nuts harvested from similarly aged trees in various forest regions than between batches harvested from differently aged trees in the same forest region. Our findings suggest that the plumpness of hornbeam nuts is more likely to be determined by local habitat conditions than the age of the tree stand.

2. In the group of the analyzed physical parameters of common hornbeam nuts, nut width was most highly correlated with nut mass (R = 0.727), whereas nut thickness was least correlated with terminal velocity (R = 0.044). A comparison of basic dimensions revealed the strongest correlations (R = 0.528) between nut width and length.

3. The results of this study indicate that hornbeam nuts should be separated with the use of mesh screens with round openings to obtain material characterized by similar mass. The most satisfactory results are obtained when hornbeam nuts are passed through screens with round openings with a diameter of 5 mm and 6 mm.

References

AGUINAGALDE I., HAMPE A., MOHANTY A., MARTIN J.P., DUMINIL J., 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.

ALTUNTAŞ E., ÖZGÖZ E., TAŞER Ö.F. 2005. *Some physical properties of fenugreek (Trigonella foenum-graceum L.) seeds*. Journal of Food Engineering, 71: 37–43.

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

BORATYŃSKI A., BORATYŃSKA K., MAZUR M., MARCYSIAK K. 2007. *Seed involucre variation in Carpinus betulus (Corylaceae) in Poland*. Acta Biologica Cracoviensia Sereies Botanica, 49(1): 103–111.

BURACZYK W. 2010. *Seed characteristics and morphological features of Scots pine (Pinus sylvestris L.) seedlings*. Leśne Prace Badawcze, 71(1): 13–20.

ÇALIŞIR S., ÖZCAN M., HACISEFEROĞULLARI H., YILDIZ M.U. 2005. *A study on some physico-chemical properties of Turkey okra (Hibiscus esculenta L.) seeds*. Journal of Food Engineering, 68: 73–78.

CZAPRACKI M., HOLUBOWICZ R. 2010. *Some factors influencing the germination of the common hornbeam (Carpinus betulus L.) seeds*. Bulletin UASVM Horticulture, 67(1): 422–429.

CZERNIK Z. 1993. *Studies of geometrical properties of silver fir seeds*. Sylwan, 8: 57–64.

DAVIES R.M., EL-OKENE A.M. 2009. *Moisture-dependent physical properties of soybeans*. International Agrophysics, 23: 299–303.

DRAGOMIR P., SZEKELY G. 2011. *Hornbeam trees in the parks of Timisoara*. Journal of Horticulture, Forestry and Biotechnology, 15(1): 47–49.

FRĄCZEK J. 1999. *Tarcie ziarnistych materiałów roślinnych*. Zeszyty Naukowe Akademii Rolniczej im. H. Kołłątaja w Krakowie, Rozprawy, 252.

GEODECKI M., GRUNDAS S. 2003. *Characterization of geometrical features of single winter and spring wheat kernels*. Acta Agrophysica, 2(3): 531–538.

GROCHOWICZ J. 1994. *Maszyny do czyszczenia i sortowania nasion*. Wydawnictwo Akademii Rolniczej, Lublin.

HORABIK J. 2001. *Physical attributes of loose plant material which are significant during storage*. Acta Agrophysica, 54.

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

KABAS O., YILMAZ E., OZMERZI A., AKINCI İ. 2007. *Some physical and nutritional properties of cowpea seed (Vigna simensis L.)*. Journal of Food Engineering 79: 1405–1409.

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., POZNAŃSKI A. 2013. *Variability and correlation of selected physical attributes of small-leaved lime (Tilia cordata Mill.) seeds*. Sylwan, 157(1): 39–46.

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.

MARKOWSKI M., ŻUK-GOŁASZEWSKA K., KWIATKOWSKI D. 2013. *Influence of variety on selected physical and mechanical properties of wheat*. Industrial Crops Products, 47: 113–117.

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

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

Nasiennictwo leśnych drzew i krzewów iglastych. 1995. Ed. A. Załęski. Oficyna Edytorska „Wydawnictwo Świat”, Warszawa.

NORDEN N., DAWS M.I., ANTOINE C., GONZALEZ M.A., GARWOOD N.C., 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.

OMOBUWAJO T.O., SANNI L.A., OLAJIDE J.O. 2000. *Physical properties of ackee apple (Blighia sapida) seeds*. Journal of Food Engineering, 45: 43–48.

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.

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*. Helion, Gliwice.

RYBIŃSKI W., SZOT B., RUSINEK R., BOCIANOWSKI J. 2009. *Estimation of geometric and mechanical properties of seeds of Polish cultivars and lines representing selected species of pulse crops*. International Agrophysics, 23: 257–267.

SADOWSKA U., ŻABIŃSKI A. 2011. *Influence of mixed sowing of yellow lupine with gymnosperm barley on the selected physical properties of seeds*. Inżynieria Rolnicza, 6(131): 187–195.

SÁNCHEZ-MENDOZA J., DOMÍNGUEZ-LÓPEZ A., NAVARRO-GALINDO S., LÓPEZ-SANDOVAL J.A. 2008. *Some physical properties of Roselle (Hibiscus sabdariffa L.) seed as a function of moisture content*. Journal of Food Engineering, 87: 391–397.

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.

SUSZKA B., MULLER C., BONNET-MASIMBER M. 2000. *Nasiona leśnych drzew liściastych od zbioru do siewu*. Wydawnictwo Naukowe PWN, Warszawa-Poznań.

TYLEK P. 2011. *Analysis of aerodynamic properties of common fir and common beech*. Inżynieria Rolnicza, 6(131): 247–253.

UPADHAYA K., PANDEY H.N., 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.

WESOŁOWSKI T., ROWIŃSKI P., MAZIARZ M. 2015. *Interannual variation in tree seed production in a primeval temperature forest: does masting prevail?* European Journal of Forest Research, 134: 99–112.

ZHU Z., XU Y., WANG S. 2014. *The causes of European hornbeam seed dormancy and methods of breaking dormancy*. Journal of Food, Agriculture & Environment, 12(2): 1149–1152.