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CORRELATIONS BETWEEN BASIC PHYSICAL PARAMETERS OF NUTS AND THE WEIGHT OF COMMON BEECH (*FAGUS SYLVATICA* L.) SEEDS

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Abstract

Selected physical attributes of common beech nuts harvested from four tree stands in northern Poland were determined. Seeds were manually extracted from every nut. Seeds and nuts were weighed, and the results were used to determine the ratio of seed weight to nut weight, which described the degree of nut filling. Physical parameters and the calculated coefficients were compared by the t-test for independent samples, analysis of variance, correlation analysis and linear regression analysis. The following ranges of variation were reported in the physical attributes of nuts and the coefficients of common beech seeds: critical transport velocity of nuts – from 6.33 to 11.28 m s^{-1}, nut thickness – from 4.76 to 9.86 mm, nut width – from 6.46 to 13.54 mm, nut length – from 12.63 to 21.62 mm, angle of sliding friction of nuts – from 15.67 to 26.67°, nut weight – from 93.0 to 513.7 mg, coefficient of sliding friction of nuts – from 0.28 to 0.50, seed weight – from 11.0 to 374.8 mg, and ratio of seed weight to nut weight – from 0.08 to 0.88. The majority of nuts contained one seed (average weight of 195.36 mg), and only 2.3% of nuts contained two seeds (average weight of 103.11 mg). The attribute that was most highly correlated with the ratio of seed weight to nut weight was seed weight (0.685), followed by critical transport velocity (0.527) and weight of nuts (0.493). The results indicate that common beech seeds would be processed most effectively in vibration-pneumatic separators or, alternatively, in pneumatic separators where nut fractions obtained with the use of mesh screens can be sorted separately.

Symbols:
k_m – ratio of seed weight to nut weight,
m – nut weight, mg,
m_s – seed weight, mg,
SD – standard deviation of trait,
T, W, L – nut thickness, width and length, mm,

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v – critical transport velocity of nuts, m s^{-1},
V_s – coefficient of trait variation, %,
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.

Introduction

The common beech (*Fagus sylvatica* L.) is a deciduous tree that reaches up to 45 m in height and 2.2 m in diameter at breast height (SUSZKA et al. 2000). The species thrives in a temperate marine climate, and its geographic range covers all of Central and Western Europe (DITTMAR et al. 2003, OHEIMB et al. 2005, BOLTE et al. 2007, MAGRI 2008, JAWORSKI 2011, BRUS et al. 2012). The common beech is a shade tolerant species with a preference for habitats characterized by high humidity and high soil moisture levels, but it avoids excessively wet and dry soils. In most Polish habitats, the common beech is a predominant tree species or it is encountered in mixed-tree stands (JAWORSKI 2011).

The common beech is a relatively slow-growing species that begins to produce seeds (nuts) at the age of 60–80 years in dense stands or 40–50 years in open stands. The fruit are small triangular nuts covered by a brown, relatively thin and flexible coat. Most nuts contain one, sometimes two seeds with an outer seed coat (SUSZKA et al. 2000, JAWORSKI 2011). Nuts mature in September and October. They are produced at irregular intervals, generally every 5–10 years (SUSZKA et al. 2000, DITTMAR et al. 2003, HILTON, PACKHAM 2003, ÖVERGAARD et al. 2007). This reproduction strategy prevents an excessive increase in populations of animals that feed on beech nuts, and it increases the number of seeds that are stored by animals in various locations (RUSCOE et al. 2005, BOGDZIEWICZ, WRÓBEL 2012). In a good year, approximately four tons of beech nuts can be harvested per hectare, and nuts are produced by trees as old as 200 years (SUSZKA et al. 2000, DITTMAR et al. 2003, HILTON, PACKHAM 2003, ÖVERGAARD et al. 2007). Nut yield is correlated with nut vitality, and the greater the yield, the higher the quality of the resulting seed material (BODYŁ, SUŁKOWSKA 2007).

Trees of the same species can produce variously-sized seeds. Both large and small seeds play an important role in the preservation of genetic diversity (FALLERI, PACELLA 1997). TYLEK (2010) reported a significant correlation between the weight and germination capacity of nuts, which can be attributed to a high percentage of heavy and well-developed nuts. Therefore, it can be presumed that the germination energy and germination capacity of common beech nuts is determined by the ratio of seed weight to nut weight.

The objective of this study was to determine correlations between the physical parameters of common beech nuts and the ratio of seed weight to nut weight for the needs of seed separation processes.

Materials and Methods

The experimental material comprised four batches of common beech nuts from a seed extraction plant in Jedwabno. Nuts were harvested in 2011 from variously-aged tree stands in two forest regions of northern Poland. The analyzed batches were harvested from the following tree stands:

a) registration No. MP/1/10732/05, category of seed propagation material – from an identified source, region of origin – 251, municipality – Biskupiec, geographic location – 53.56°N, 20.59°E, forest habitat – fresh forest, age – 114 years (symbol: B-1),

b) registration No. MP/1/2590/05, category of seed propagation material – from an identified source, region of origin – 157, municipality – Prabuty, geographic location – 53.50°N, 19.11°E, forest habitat – fresh mixed forest, age – 125 years (symbol: B-2),

c) registration No. MP/2/31347/05, category of seed propagation material – qualified, region of origin – 103, municipality – Godkowo, geographic location – 54.06°N, 19.54°E, forest habitat – fresh forest, age – 134 years (symbol: B-3),

d) registration No. MP/1/43654/05, category of seed propagation material – from an identified source, region of origin – 106, municipality – Grunwald, geographic location – 53.37°N, 20.07°E, forest habitat – fresh mixed forest, age – 145 years (symbol: B-4).

Nut batches were divided by halving (*Nasiennictwo leśnych drzew*... 1995). The analyzed batches 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 resulting nut samples had the following size: B-1 – 118, B-2 – 120, B-3 – 116, B-4 – 115.

Critical transport velocity of common beech seeds was determined in the Petkus K-293 pneumatic classifier (VEB PETKUS Wutha/Thur, Germany). Seed dimensions were determined with the use of the MWM 2325 workshop microscope (PZO Warszawa, Poland) (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 – $R_a =$ $= 0.42$ μm). The angle of sliding friction was determined as the average angle produced by three nut arrangement patterns: with the longitudinal axis perpendicular and parallel to the direction of inclination, and with the tip directed towards the top and the bottom of the friction plane. Nut weight was determined on the WAA 100/C/2 laboratory scale (RADWAG Radom, Polska). Seeds were extracted manually from nuts and weighed on the above laboratory scale. All measurements were performed according to the methods previously described by KALINIEWICZ et al. (2011) and KALINIEWICZ and POZNAŃSKI (2013).

The coefficient of sliding friction was determined for every nut based on the following equation:

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

The ratio of seed weight to nut weight was calculated with the use of the below formula:

$$k_m = \frac{m_s}{m} \tag{2}$$

Nuts were divided into two groups based on the ratio of seed weight to nut weight: poorly filled nuts (k_m<0.6) and well-filled nuts (k_m≥0.6).

The results were processed with the use of Statistica PL v. 10 application based on general statistical procedures, including 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 lowest average values of critical transport velocity, nut thickness, nut width and nut weight were noted in batch B-3 (Table 1). B-3 nuts were least plump, and they were also characterized by the highest average angle of sliding friction. The thickest and the widest nuts were reported in batch B-4, the longest nuts – in batch B-2, and the heaviest nuts – in batch B-1. In a comparison of physical parameters (Table 1), significant differences between batches were noted only in the values of the angle of sliding friction. The remaining attributes differed only locally, and the most pronounced differences were noted in nut length.

The statistical distribution of the physical attributes of all four nut batches and the calculated coefficients is given in Table 2. Critical transport velocity ranged from 6.33 to 11.28 m s^{-1}, and its average value was similar to that noted by KALINIEWICZ et al. (2014) and around 7% lower than that reported by TYLEK (2011). The analyzed nuts were classified as plump based on their average dimensions and weight. They were approximately 25% heavier, 5% longer and 7% wider than the nuts harvested from 120-year-old trees in Młynary (region

Table 1

Variations in the physical attributes of beech nuts with an indication of significant differences

Physical attribute	Nut batch			
	B-1 x±SD	B-2 x±SD	B-3 x±SD	B-4 x±SD
v	9.40 ± 0.99^{a}	9.33 ± 0.87^{ab}	9.09 ± 1.08^{b}	9.17 ± 0.89^{ab}
T	7.32 ± 0.91^{ab}	7.28 ± 0.80^{b}	7.19 ± 0.70^{b}	7.53 ± 0.94^{a}
W	9.67 ± 0.94^{ab}	9.61 ± 0.90^{b}	9.16 ± 1.10^{c}	9.88 ± 0.90^{a}
L	16.75 ± 1.54^{b}	17.17 ± 1.56^{a}	16.99 ± 1.50^{ab}	16.70 ± 1.47^{b}
γ	21.64 ± 0.95^{b}	20.47 ± 1.52^{d}	22.05 ± 2.15^{a}	21.19 ± 1.15^{c}
m	306.23 ± 76.53^{a}	299.82 ± 65.24^{a}	276.03 ± 64.65^{b}	292.80 ± 62.87^{ab}

$^{a, b, c, d}$ – different letters denote significant differences in the evaluated attribute between batches.

of origin – 103) and evaluated by BODYŁ and SUŁKOWSKA (2007). No significant differences were reported between the analyzed nuts and the material examined by TYLEK (2010) and KALINIEWICZ et al. (2014). The length and width of beech nuts were similar to those determined in the seeds of *Cucurbita moschata* Duch. (JACOBO-VALENZUELA et al. 2011). The average length of beech nuts was comparable to that of pumpkin seeds (JOSHI et al. 1993) and kidney beans (ALTUNTAS, DEMIRTOLA 2007).

Table 2

Statistical distribution of physical attributes and coefficients

Physical attribute/ coefficient	x_{min}	x_{max}	x	SD	V_s
v	6.33	11.28	9.25	0.97	10.47
T	4.76	9.86	7.32	0.84	11.42
W	6.46	13.54	9.58	0.99	10.29
L	12.63	21.62	16.91	1.53	9.03
γ	15.67	26.67	21.34	1.62	7.58
m	93.0	513.7	293.80	68.18	23.20
μ	0.28	0.50	0.39	0.03	8.38
m_s	11.0	374.8	195.44	55.38	28.33
k_m	0.08	0.88	0.66	0.08	12.17

The angle of sliding friction of a steel friction plate ranged from 0.28 to 0.50, with an average of 0.39. The average value was approximately 24% lower than that reported by TYLEK (2006, 2010) and approximately 11% lower than that presented by KALINIEWICZ et al. (2014). The above differences can be probably attributed to variations in the porosity of friction plates. KALINIEWICZ et al. (2014) used a steel plate with the porosity of R_a = 0.48 μm, whereas in this study, plate porosity was R_a = 0.42 μm. The average coefficient of sliding friction of the analyzed beech nuts resembled that noted on a similar friction plate for pumpkin seeds (JOSHI et al. 1993), ackee seeds (OMOBUWAJO et al.

2000), chick peas (KONAK et al. 2002), lentils (AMIN et al. 2004), fenugreek seeds (ALTUNTAŞ et al. 2005), okra seeds (ÇALIŞIR et al. 2005) and psyllium seeds (AHMADI et al. 2012).

Approximately 2.3% of the analyzed nuts contained two seeds. The significance of differences in physical attributes between nuts containing one and two seeds is presented in Table 3. Nuts with two seeds were characterized by somewhat higher weight and higher critical transport velocity than nuts containing one seed, but no significant differences were observed between those two groups of nuts. Differences were reported in the weight of seeds from both types of nuts, and they can be attributed to the availability of free space inside nuts containing one and two seeds. Despite somewhat higher average combined weight of seeds in dual-seed nuts (206.22 mg) than in single-seed nuts (195.18 mg), no significant differences were observed between those groups. Nuts containing two seeds cannot be separated from the analyzed material with the use of conventional separators. The above poses a disadvantage for tree nurseries because a dual-seed nut can give rise to two weaker seedlings, one of which will have to be removed with time.

Table 3

Significance of differences in physical attributes between two types of nuts

Physical attribute/ coefficient	Nuts	
	with one seed x±SD	with two seeds x±SD
v	9.24±0.96[a]	9.53±1.15[a]
T	7.32±0.84[a]	7.32±0.84[a]
W	9.57±0.99[a]	9.88±1.01[a]
L	16.92±1.53[a]	16.66±1.45[a]
γ	21.33±1.62[a]	21.79±1.48[a]
m	293.58±68.56[a]	303.17±51.27[a]
μ	0.39±0.03[a]	0.40±0.04[a]
m_s	195.18±55.74[a]	103.11±26.74[b]
k_m	0.66±0.08[a]	0.68±0.04[a]

[a, b] – different letters denote significant differences in the evaluated attribute between nuts with one and two seeds.

The analyzed material comprised 10.1% poorly filled nuts (k_m<0.6) and 89.9% well-filled nuts (k_m≥0.6). An analysis of linear correlations between the physical attributes of nuts and the ratio of seed weight to nut weight (Table 4) revealed that angle of sliding friction and coefficient of sliding friction were least correlated with the remaining parameters. The above results validate the observation made by TYLEK (2006) that the frictional properties of common beech nuts cannot be regarded as the major separating criterion in the process of improving nut germination capacity and separating plump nuts. Significant correlations were noted between thickness and width and between weight and critical transport velocity vs. dimensions of beech nuts. The above results corroborate the findings of TYLEK (2010) and KALINIEWICZ et al. (2014). Nut weight was most highly correlated with seed weight (0.963). Significantly high (above 0.5) and comparable values of the correlation coefficient were noted between seed weight vs. the critical transport velocity of nuts, nut thickness and nut width. As expected, seed weight was most highly correlated with the ratio of seed weight to nut weight (0.685). Critical transport velocity of nuts was also strongly correlated with the ratio of seed weight to nut weight (0.527). The above results corroborate the observation made by TYLEK (2011) that critical transport velocity should not be used as a separation criterion in beech seeds. Nut dimensions (excluding, to a limited degree, nut width) did not influence the ratio of seed weight to nut weight, therefore, screen separators should be only used to calibrate seeds, which increases the efficiency of other separation processes, in particular pneumatic separation (*Nasiennictwo leśnych drzew*... 1995, TYLEK 2010). In view of very strong correlations between the ratio of seed weight to nut weight vs. nut weight and critical transport velocity, the use of vibration-pneumatic separators, which sort seeds based on differences in their density and critical transport velocity, could significantly improve the separation efficiency of common beech nuts (GROCHOWICZ 1994).

Table 4

Coefficients of linear correlation between the physical attributes of beech nuts

Physical attribute	T	W	L	γ	m	μ	m_s	k_m
v	**0.099**	**0.162**	-0.003	**-0.154**	**0.465**	**-0.157**	**0.527**	**0.527**
T	1	**0.531**	**0.315**	**-0.145**	**0.624**	**-0.147**	**0.527**	0.049
W		1	**0.337**	-0.033	**0.635**	-0.034	**0.562**	**0.118**
L			1	-0.055	**0.520**	-0.055	**0.423**	-0.017
γ				1	**-0.149**	**0.999**	**-0.157**	**-0.159**
m					1	**-0.151**	**0.963**	**0.493**
μ						1	**-0.159**	**-0.162**
m_s							1	**0.685**

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

Significant correlations between the ratio of seed weight to nut weight vs. the critical transport velocity and weight of beech nuts are presented in Figure 1. In regression equations, the coefficient of determination reached 0.278 in the first comparison and 0.244 in the second comparison. The noted results are satisfactory for biological materials and in view of the number of analyzed measurements. The presented equations can be used to plan separation processes and calibrate sorting devices. The separating threshold of a pneumatic separator should be theoretically set at approximately 8.1 m s^{-1} to obtain well-filled nuts (k_m≥0.6), whereas separators with a weight detection option should support the separation of nuts weighing up to 200 mg. A certain number of well-filled nuts would be removed from the separated material, which implies that a certain percentage of poorly filled nuts would remain in the material (around 7% of well-filled nuts and 45% of weakly-filled nuts, if a pneumatic separator is used).

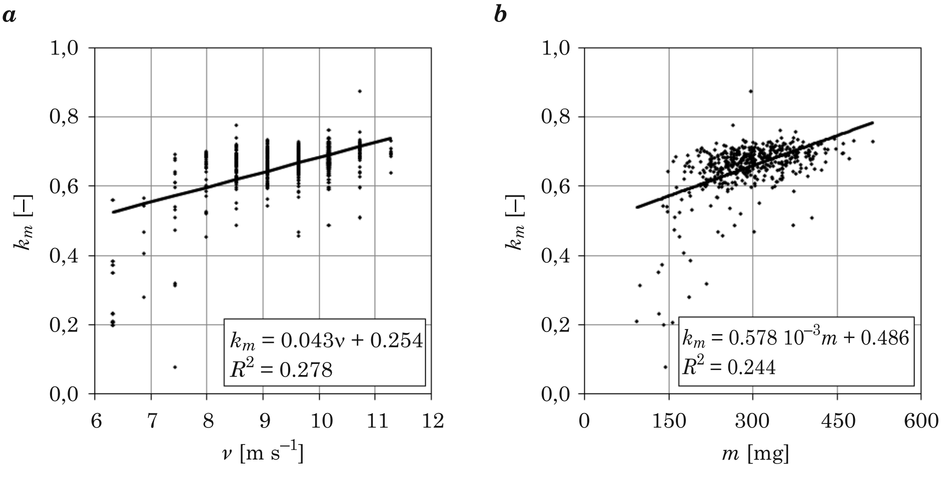

Fig. 1. Correlations between the ratio of seed weight to nut weight vs. the critical transport velocity (*a*) and weight of beech nuts (*b*)

Conclusions

1. Common beech nuts contain one or two seeds. Nuts with two seeds (around 2.3% of the analyzed nuts) were somewhat heavier and wider, but they did not differ significantly from the remaining nuts, therefore, they could not be separated with the use of conventional seed separators. In nuts containing two seeds, the average weight of each seed was nearly half that of seeds from nuts containing a single seed.

2. The weight of common beech seeds was most highly correlated with the weight of nuts (correlation coefficient of 0.963). In the group of the remaining physical attributes, seed weight was most highly correlated with nut width (0.562) and least correlated with the angle of sliding friction of nuts (-0.157).

3. Common beech nuts could be effectively separated with the use of vibration-pneumatic separators due to strong correlations between the ratio of seed weight to nut weight vs. the critical transport velocity and weight of nuts. Pneumatic separators can also be applied, and the use of screen separators for preliminary sorting could be considered.

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