TECHNICAL SCIENCES
Abbrev.: Techn. Sc., 2011, 14(1)

ANALYSIS OF CORRELATIONS BETWEEN SELECTED PHYSICAL ATTRIBUTES OF SCOTS PINE SEEDS

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K e y w o r d s: Scots pine, seeds, separation properties, cleaning, sorting.

A b s t r a c t

Critical transport velocity, the thickness, width, length and the angle of sliding friction of Scots pine seeds harvested from three seed banks (conservation seed stand, commercial seed stand and seed plantation) were determined. The investigated attributes were compared by single classification analysis of variance, correlation, single-variable and multivariate regression analysis. The analyzed seed traits differed significantly between the specimens from the examined seed banks. The equations describing the correlations between the studied attributes were characterized by relatively low percentages of explained variation, which renders them unfit for designing seed and separation models.

ANALIZA WSPÓŁZALEŻNOŚCI WYBRANYCH CECH FIZYCZNYCH NASION SOSNY ZWYCZAJNEJ

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S ł o w a k l u c z o w e: sosna zwyczajna, nasiona, cechy rozdzielcze, czyszczenie, sortowanie.

A b s t r a k t

Wyznaczono prędkość krytyczną unoszenia, grubość, szerokość, długość i kąt tarcia ślizgowego nasion sosny zwyczajnej, zebranych z trzech odmiennych baz nasiennych (wyłączony drzewostan nasienny, gospodarczy drzewostan nasienny i plantacja nasienna). Porównywano te cechy, wykorzystując analizę wariancji z klasyfikacją pojedynczą, korelację oraz regresję jednej zmiennej i wielu zmiennych. Stwierdzono, że w większości przypadków analizowane cechy nasion z odmiennych baz nasiennych różnią się statystycznie. Równania współzależności między określanymi cechami charakteryzują się stosunkowo niskim procentem wyjaśnionej zmienności, co właściwie wyklucza ich zastosowanie do budowania modeli nasion i procesów rozdzielczych.

Symbols:
F – seed cross-sectional area, mm^2,
L – seed length, mm,
S – standard deviation of trait,
T – seed thickness, mm,
v – critical transport velocity of seeds, m s^{-1},
V – seed volume, mm^3,
W – seed width, mm,
x – average value of trait,
x_{max} – maximum value of trait,
x_{min} – minimal value of trait,
α, β – Donev's shape factors,
γ – angle of sliding friction, °,
χ^2_{cal} – calculated value of statistical parameter,
χ^2_{α} – value from statistical table at significance level α = 0.05.

Introduction

The pine is a monoecious tree that begins to produce seeds at the estimated age of 15 years (isolated trees), generally around the age of 35 years. Large quantities of pine cones are produced every 3–4 years (MURAT 2002, *Nasiennictwo leśnych drzew...* 1995). Pine seeds are obtained from selected trees, conservation seed stands, commercial seed stands, seed plantations and farms. The largest quantity of seeds is harvested from commercial stands (around 72%) and conservation stands (around 14%) (MURAT 2002).

In principle, forest reproductive material is never mixed, and it is generally used only in the region of origin (MURAT 2005). Scots pine seeds are usually contaminated with organic pollutants only. Such impurities are produced in the process of husking and dewinging, and they are easily removed. Pollutants are separated into fractions using a mesh sieve, and they are cleaned in a pneumatic separator to remove empty and undeveloped seeds (SARNOWSKA, WIĘSIK 1998, *Nasiennictwo leśnych drzerw...* 1995). Seed producers are often faced with a dilemma as to whether seeds of the same species harvested from different seed banks should be purified and sorted with the application of the same equipment settings or whether a different set of settings should be selected individually for every batch.

The aim of this study was to determine the key separation properties (critical transport velocity, dimensions, angle of sliding friction) of Scots pine seeds and the correlations between the investigated attributes for the needs of the seed cleaning and sorting process.

Materials and Methods

The experimental material comprised Scots pine seeds harvested from cones supplied to the husking plant in Ruciane Nida. Cones were harvested from three seed banks:

a) conservation seed stand, 132 years, Maskulińskie Forest Inspectorate, Guzianka Forest District 28/16/045, forest site – fresh mixed coniferous forest, rusty soil (marked as WDN),

b) commercial seed stand, 137 years, Maskulińskie Forest Inspectorate, Śniardwy Forest District 28/16/025, forest site – fresh mixed coniferous forest, rusty soil (marked as GDN),

c) seed plantation, 11–15 years, Łomża Forest Inspectorate, Podgórze Forest District, forest site – fresh mixed broadleaved forest, brown soil (marked as PN).

Roughly 2 kg of pine cones were randomly selected from each batch of the harvested material. Seeds were husked by heating the cones repeatedly in a stream of air and cooling them at low temperature. The investigated samples were characterized by a low number of seeds which were dewinged by rubbing in a linen bag. After pollutant separation, the material was spread on a table and divided by halving (*Nasiennictwo leśnych drzew...* 1995) to produce research samples of around 300 seeds each. The selected method produced samples of uneven size: WDN – 291, GDN – 307, PN – 309.

Every sample was initially divided into fractions using the Petkus K-293 pneumatic classifier with the precision of 0.11 m/s, and critical transport velocity was determined for the mean of the class interval in each group. The seeds from every fraction were placed on a transparent plate, and their length and width was measured under an MWM 2325 workshop microscope. The third dimension (thickness) was determined using a dial indicator device with measurement precision of 0.01 mm. The angle of sliding friction was determined on an inclined plane with an adjustable angle of inclination and a friction plate of ST3S steel. Measurement precision was 1°. A slicing test was performed to determine seed fullness.

It was assumed that the shape of Scots pine seeds resembles an ellipsoid. The cross-sectional area F and volume V of individual seeds was calculated using the below formulas:

$$F = \frac{\pi \cdot W \cdot T}{4}$$

$$V = \frac{\pi \cdot L \cdot W \cdot T}{6}$$

Due to a distinctive axis of rotation, Donev's shape factors (FRĄCZEK, WRÓBEL 2006) were applied to determine the shape of the studied seeds. The axis of rotation and seed length overlap, therefore, Donev's shape factors took on the following form:

$$\alpha = \frac{L}{T}$$

$$\beta = \frac{W}{T}$$

The effectiveness of separation of undeveloped seeds was calculated based on the ratio of the number of seeds separated from the material to the total number of undeveloped seeds (5% seeds with the smallest volume). The loss of plump seeds was determined based on the ratio of developed seeds separated from the material to the total number of developed seeds (difference between the number of seeds in the sample and the number of undeveloped seeds).

The results were processed statistically using Winstat and Statistica applications with the involvement of the following procedures: determination of consistency between variable distribution and normal distribution, analysis of variance, correlation, single-variable and multivariate regression analysis and stepwise regression to eliminate non-significant factors.

Results and discussion

The results of the slicing test revealed that most of the analyzed pine seeds were full without any signs of spoilage. The statistical parameters describing the seeds' physical properties and the results of Pearson's χ^2 test are presented in Table 1. At the adopted level of significance (α = 0.05), there were no grounds to refute the theory that empirical distribution is consistent with normal distribution. The least developed seeds were harvested from the commercial seed stand. They were characterized by the highest average critical transport velocity and the smallest angle of sliding friction. Seed dimensions were generally consistent with published data (BURACZYK 2010, GIL, KINELSKI 2003, TYLEK 1998).

Table 1
Statistical calculations of critical transport velocity, dimensions and angle of sliding friction of Scots pine seeds

Parameter	x_{min}	x_{max}	x	S	χ^2_{cal}	χ^2_{α}
Conservation seed stand – WDN						
v	3.58	7.98	6.68^B	0.787	6.321	7.815
T	1.03	1.84	1.45^B	0.126	5.905	7.815
W	2.28	2.89	2.59^B	0.083	7.542	7.815
L	3.99	5.67	4.92^A	0.169	5.390	5.992
γ	27	40	33.55	2.235	5.628	5.992
Commercial seed stand – GDN						
v	5.23	7.98	6.99^A	0.513	5.841	5.992
T	1.05	1.68	1.40^C	0.119	6.474	7.815
W	2.08	2.87	2.47^C	0.145	2.063	9.488
L	3.40	5.36	4.59^C	0.399	7.627	7.815
γ	25	40	33.28^B	2.514	6.985	7.815
Seed plantation – PN						
v	4.13	7.98	6.77^B	0.774	7.744	7.815
T	1.20	1.92	1.54^A	0.135	9.036	9.448
W	2.13	3.18	2.70^A	0.159	2.859	5.992
L	3.29	5.63	4.79^B	0.314	7.792	7.815
γ	27	41	33.92^A	2.711	4.779	5.992

$^{A, B, C}$ – uppercase letters in the superscript indicate significant variations at the level of 0.01

A single classification analysis of variance was performed to validate the significance of variations between the average values. A comparison of seeds harvested from the conservation stand (WDN) and the commercial stand (GDN) yielded interesting results since parent trees were almost even-aged and they grew in similar habitats. Insignificant differences between the above seed groups were reported only in respect of the angle of sliding friction. No significant variations were noted in a comparison of critical transport velocity and angle of sliding friction in WDN and PN seed groups. The above results indicate that in most cases, the physical attributes of seeds harvested from the investigated stands were marked by significant variations.

The following seed parameters are given in Table 2: Donev's shape factors, cross-sectional area and volume. The above parameters were subjected to a single classification analysis of variance, and the results are presented in Table 2. Significant variations were not reported only with regard to shape factor β of seeds harvested from the commercial stand and the seed plantation. The average values of cross-sectional area and seed volume indicate that the plumpest seeds were harvested from the plantation, while the least developed seeds were obtained from the commercial stand. Conservation stand seeds were characterized by the highest value of shape factors α and β.

Table 2

Shape factors (α, β), cross-sectional area (F) and volume (V) of Scots pine seeds

Parameter	x_{min}	x_{max}	x	S
Conservation seed stand – WDN				
α	2.79	4.49	3.41^{A}	0.269
β	1.46	2.38	1.80^{Aa}	0.147
F	1.84	3.99	2.96^{B}	0.303
V	4.91	15.02	9.72^{B}	1.206
Commercial seed stand – GDN				
α	2.32	4.50	3.29^{B}	0.331
β	1.41	2.16	1.77^{b}	0.126
F	1.72	3.76	2.73^{C}	0.345
V	4.08	12.50	8.37^{C}	1.433
Seed plantation – PN				
α	2.15	4.02	3.12^{C}	0.289
β	1.45	2.43	1.76^{B}	0.156
F	2.26	4.52	3.28^{A}	0.398
V	5.83	16.39	10.50^{A}	1.649

$^{A, B, C}$ – uppercase letters in the superscript indicate significant variations at the level of 0.01
$^{a, b, c}$ – lowercase letters in the superscript indicate significant variations at the level of 0.05

The smallest and, presumably, the least developed seeds have to be eliminated from every population because their reserve nutrient substances do not support full seedling development (*Nasiennictwo leśnych drzew...* 1995). The allowable loss during seed sorting was adopted at 5%, and the sorting efficiency of undeveloped seeds and the loss of developed seeds, determined based on seed characteristics (critical transport velocity, length, width, thickness and angle of sliding friction), are given in Table 3. The analyzed seed batches were characterized by different classification limits, thus validating the principle that every seed batch should be processed individually, and the settings of seed sorting and cleaning equipment should be customized according to need (*Nasiennictwo leśnych drzew...* 1995). The above principle is further supported by the results of calculations performed after the separation of mixed seed batches. If separation efficiency were to be evaluated based on individual seed attributes, the GDN batch would yield a relatively high number of undeveloped seeds, whereas few such seeds would be produced by PN and WDN groups. The analyzed batch would also be marked by the highest loss of plump seeds. The above indicates that the majority of seeds eliminated from the population would comprise the material harvested from the commercial stand, including both developed and undeveloped seeds. The noted results also suggest that if the smallest seeds were to be removed based on a single attribute, the separation process should be carried out with the involvement of graders (which separate seeds based on their length) that effectively remove undeveloped seeds, thus minimizing plump seed loss. The results of this study also validate the use of sieves in the process of cleaning and sorting Scots pine seeds. Pneumatic and friction separators should not be used as the only separating devices. Such equipment, in particular pneumatic separators, are applied to remove fine wing parts and empty seeds from husked material.

Table 3

Separation efficiency of undeveloped seeds extracted from Scots pine seed material

Classification limit	Separation efficiency of undeveloped seeds [%]	Loss of plump seeds [%]
	WDN	
v=5.23 m s^{-1}	0	5.43
L=4.67 mm	46.67	2.90
W=2.45 mm	26.67	3.98
T=1.26 mm	60.00	2.17
γ=30°	13.33	4.71
	GDN	
v=6.33 m s^{-1}	62.50	2.05
L=3.76 mm	68.75	1.71
W=2.26 mm	56.25	2.39
T=1.22 mm	43.75	3.07
γ=30°	6.25	5.12
	PN	
v=5.78 m s^{-1}	6.25	5.15
L=4.20 mm	62.50	2.06
W=2.49 mm	56.25	2.41
T=1.34 mm	37.50	3.44
γ=30°	18.75	4.46
	Total	
v=5.78 m s^{-1}	WDN – 13.33; GDN – 0; PN – 6.25	WDN – 7.97; GDN – 0.67; PN – 6.82
L=4.11 mm	WDN – 6.67; GDN – 93.75; PN – 37.50	WDN – 0; GDN – 7.90; PN – 0.68
W=2.31 mm	WDN – 6.67; GDN – 75.00; PN – 12.50	WDN – 0; GDN – 11.00; PN – 0
T=1.26 mm	WDN – 46.67; GDN – 81.25; PN – 12.50	WDN – 2.53; GDN – 6.52; PN – 0
γ=30°	WDN – 13.33; GDN – 6.25; PN – 12.50	WDN – 3.62; GDN – 6.87; PN – 4.10

The coefficients of linear correlation between the analyzed traits and the calculated parameters are presented in Table 4. The critical values of transport velocity, seed length, cross-sectional area, volume, angle of sliding friction and shape factors α and β were not exceeded. When the values of critical transport velocity and angle of sliding friction were compared against the remaining physical attributes and the calculated parameters, the resulting coefficients of correlation were very low. The highest correlation coefficient of 0.539 was observed between seed width and seed thickness. Nonetheless, the reported value is relatively low, as demonstrated by the spread of measurement points in Figure 1.

Table 4

Coefficients of linear correlation between the analyzed traits and statistical parameters of Scots pine seeds

Parameter	v	L	W	T	γ	α	β	F	V
v	1.000								
L	-0.047	1.000							
W	-0.069	0.372	1.000						
T	0.094	0.342	0.539	1.000					
γ	-0.070	0.101	0.096	0.072	1.000				
α	-0.117	0.411	-0.237	-0.711	0.004	1.000			
β	-0.163	-0.109	0.148	-0.747	-0.001	0.649	1.000		
F	0.038	0.395	0.817	0.924	0.094	-0.595	-0.443	1.000	
V	0.011	0.684	0.783	0.857	0.120	-0.318	-0.391	0.937	1.000

Critical value of the correlation coefficient – 0.065

The correlation between separation properties has to be determined for the purpose of designing seed sorting and cleaning processes (GROCHOWICZ 1994). It supports the determination of adequate separation indicators without the need to measure all investigated traits. The equations describing the studied attributes, produced by the stepwise regression analysis, are presented in Table 5. Owing to generally low percentages of explained variation, the above table lists only correlations with the highest values. As demonstrated by the correlation analysis, the equations describing critical travel velocity and angle of sliding friction were characterized by very low goodness of fit. The above applies to both single-variable and multivariate equations. The equations describing the width and thickness of Scots pine seeds produced correlations with the highest percentage of explained variation. The noted values did not exceed 34, indicating that those equations should not be applied to convert parameters.

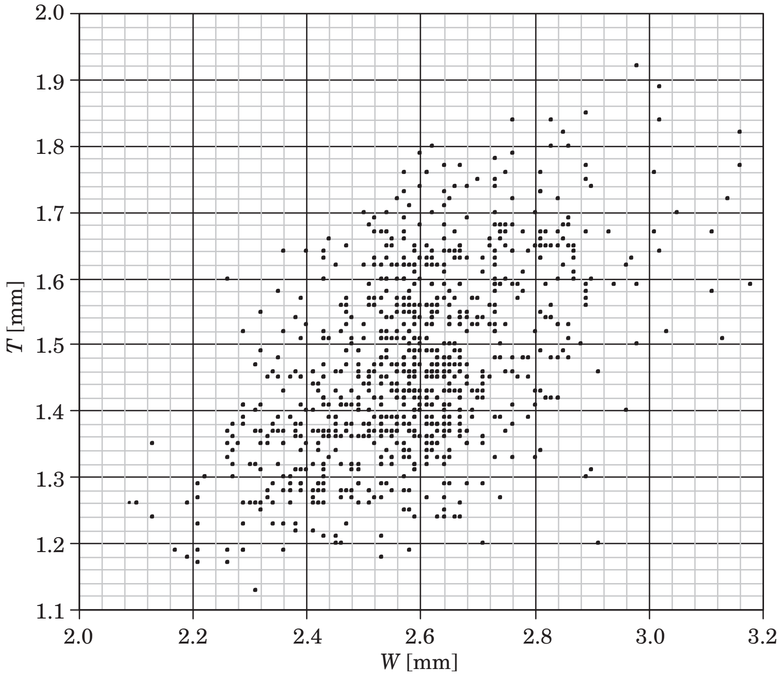

Fig. 1. Correlation between thickness T and width W of Scots pine seeds

Table 5
Single-variable and multivariate equations describing critical transport velocity, dimensions and angle of sliding friction of Scots pine seeds

Equation	Percentage of explained variation	Standard deviation of residuals
$v = -0.08\beta^3 + 7.29$	2.71	0.703
$T = 0.46W + 0.28$	29.09	0.118
$W = 0.63T + 1.66$	29.09	0.138
$L = 50.66W - 17.67W^2 + 2.06W^3 - 43.67$	18.62	0.306
$\gamma = 6.36 \cdot 10^{-4} V^3 + 32.98$	1.73	2.488
$T = 0.41W + 0.1L^2 + 0.24$	31.37	0.116
$W = 0.24L + 1.00T - 0.10L \cdot T + 0.64$	33.48	0.134
$L = 7.97W - 1.47W^2 + 0.17W \cdot T - 6.64$	20.33	0.303

Level of significance – 0.05

Conclusions

1. The correlations between the separation properties of Scots pine seeds harvested from three seed banks were characterized by high variability, and the resulting equations showed a relatively low percentage of explained

variation. For this reason, the noted correlations should not be used for the purpose of designing seed cleaning and sorting processes.

2. Seed thickness and width were the most correlated attributes of Scots pine seeds, whereas critical travel velocity and length were the least correlated traits.

3. Due to statistical variations between seed populations from different seed banks, every seed batch should be processed individually, and the settings of seed sorting and cleaning equipment should be customized according to need.

Translated by ALEKSANDRA POPRAWSKA

Accepted for print 15.04.2011

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