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THE EFFECT OF THE AGE OF SCOTS PINE (*PINUS SYLVESTRIS* L.) STANDS ON THE PHYSICAL PROPERTIES OF SEEDS AND THE OPERATING PARAMETERS OF CLEANING MACHINES

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Abstract

Critical transport velocity, the thickness, width, length, the angle of sliding friction and weight of Scots pine seeds harvested from conservation seed stands were measured. Correlations were determined between the age of parent stands (124 to 180 years old) and the above parameters of Scots pine seeds. Significant correlations were found between the age of parents stands and the weight, dimensions and the angle of sliding friction of seeds. Such a correlation was not observed for critical transport velocity. The noted correlations were presented as first-order equations which show that among the studied seed properties, average seed weight changed to the highest degree – it decreased by ca. 15% as Scots pine trees grew older.

Symbols:

m – seed weight, mg,
S – standard deviation of property,
T, W, L – seeds thickness, width and length, mm,
w – age of parent trees, years
v – critical transport velocity of seed, $m \cdot s^{-1}$,
V_s – coefficient of trait variability, %,
x – average value of property,
x_{max} – maximum value of property,
x_{min} – minimum value of property,
γ – angle of sliding friction of seed, ^{o}.

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Introduction

The initial stage of tree growth is characterized by intensive development of vegetative organs. At the fruiting stage, more nutrient resources are invested into seeds, which slows down tree height growth. At a certain age, trees stop growing in height and the aging process begins. The life processes of trees weaken, and seeds become less plump. In Poland, Scots pines enter the old-growth stage at the age of ca. 100 years (MURAT 2002, PUCHNIARSKI 2008). In the present study, the following research hypothesis was formulated: seed weight and dimensions decrease as the tree stand grows older.

Harvested cones of Scots pine are extracted, and the produced seeds are dewinged. Dewinging supports the automation of further cleaning, storage, processing and sowing processes (MURAT 2005, PUCHNIARSKI 2008). Pine seeds are cleaned and sorted with the use of mesh sieves, pneumatic separators and machines that combine both functions (SARNOWSKA, WIĘSIK 1998). Separation processes rely on the following physical attributes of seeds: thickness, width and critical transport velocity. Analyses of selected physical properties of seeds from different seed lots (KALINIEWICZ et al. 2011) reveal significant differences. For this reason, the parameters of cleaning and sorting devices should be selected individually to account for the specific characteristics of a given seed stock. The above hypothesis has been validated by MURAT (2002) and SUSZKA et al. (2000). According to the cited authors, in order to preserve the genetic material, particular attention should be paid to separating the smallest seed fraction in the process of cleaning seeds from uneven-aged stands and from different trees of an even-aged stand, to prevent the removal of high-quality seeds together with small impurities (seed wings and wing fragments, husk fragments, dust) and empty seeds.

The aim of this study was to determine the effect of the age of old-growth parent Scots pine (*Pinus sylvestris* L.) stands on selected physical properties of seeds (critical transport velocity, the thickness, width, length, the angle of sliding friction and weight) and the operating parameters of cleaning machines.

Materials and Methods

The experimental material comprised Scots pine seeds harvested from cones collected in Seed Region 206 (Maskulińskie Forest Inspectorate, Regional Directorate of State Forests in Białystok, Poland) in 2009, from the following five old-growth conservation seed stands differing in age, with the following characteristics:

a) age – 124 years, forest site – Krzyże Forest Division 28/16/045, forest habitat – fresh forest, soil – rusty (marked as WDN-124),

b) age – 132 years, forest site – Guzianka Forest Division 28/16/045, forest habitat – fresh mixed forest, soil – rusty (marked as WDN-132),

c) age – 155 years, forest site – Borek Forest Division 28/16/045, forest habitat – fresh forest, soil – rusty (marked as WDN-155),

d) age – 162 years, forest site – Guzianka Forest Division 28/16/045, forest habitat – fresh mixed forest, soil – rusty podsol (marked as WDN-162),

e) age – 180 years, forest site – Borek Forest Division 28/16/045, forest habitat – fresh mixed forest, soil – rusty (marked as WDN-180).

Roughly 2 kg of pine cones were randomly selected from each batch of the harvested material supplied to the extraction plant in Ruciane Nida. Seeds were extracted by heating the cones five times in a stream of air (air temperature – ca. 60°C, relative air humidity – ca. 40%, duration – 5 h) and cooling them at a low temperature (air temperature – –10°C, relative air humidity – 80%, duration – 1 h). All seeds were removed from open cones by breaking off husks the wings of seeds were removed by rubbing in a linen bag. After impurities had been separated, the material was spread on a table and divided by halving (*Nasiennictwo*... 1995), to obtain samples of slightly more than 100 seeds each. The selected method produced samples of size: WDN-124 – 122, WDN-132 – 125, WDN-155 – 123, WDN-162 – 120, WDN-180 – 123. Such a sample size guaranteed standard errors of the mean smaller than 0.2 $m \cdot s^{-1}$ for critical transport velocity, 0.1 mm for basic seed dimensions, 1° for the angle of sliding friction and 0.5 mg for seed weight. The relative moisture content of seeds in samples was similar, ranging from 7.6% to 8.3%.

At the first stage of the study, the critical transport velocity of seeds was determined using the Petkus K-293 pneumatic classifier within an accuracy of 0.11 $m \cdot s^{-1}$ (measurement precision of air flow rate of 1 $m3 \cdot h^{-1}$), according to the method proposed by KALINIEWICZ and TROJANOWSKI (2011).

Seed length and width were measured with the precision of 0.02 mm under an MWM 2325 workshop microscope, and seed thickness was determined with a dial indicator device, within an accuracy 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 (GPS – R_a = 0.46 μm), with the precision of 1°. The above measurements were performed as described by KALINIEWICZ et al. (2011).

The seeds were weighed on WAA 100/C/2 laboratory scales, within an accuracy of 0.1 mg.

At the second stage of the study, the separation of seeds with critical velocity below 5 $m \cdot s^{-1}$ produced samples with the following number of Scots pine seeds: WDN-124 – 117, WDN-132 – 119, WDN-155 – 116, WDN-162 – 115, WDN-180 – 118.

The results were processed statistically using Statistica PL ver. 10 application, at a significance level of $\alpha = 0.05$, with the involvement of the following methods (LUSZNIEWICZ, SŁABY 2008):

– single classification analysis of variance – to compare the mean values of the attributes of Scots pine seeds from variously aged stands. When significant differences were observed, a post-hoc procedure with Duncan's test was employed to construct homogeneous subsets;

– correlation analysis – to determine correlations between the physical attributes of Scots pine seeds and the age of the parent stand, based on Pearson's linear correlation coefficients;

– linear regression – to determine a function describing the correlation between the age of the parent stand and selected physical attributes of seeds, based on the least squares method.

Results and Discussion

An analysis of the critical transport velocity of seeds (Fig. 1) revealed that each of the five distributions representing a different stand age had a bimodal character. Seeds with critical velocity below 5 m $\cdot$ s^{-1} were found to be empty in a slicing test. Seeds with higher values of critical velocity contained embryos at different stages of development. An analysis of seeds representing five stands (Tab. 1), divided into two fractions based on their critical transport velocity (5 m $\cdot$ s^{-1}), showed that they differed significantly also with respect to weight. No significant differences were noted between the dimensions (length, width and thickness) of seeds of the two fractions. According to reference data (GROCHOWICZ 1994), the critical transport velocity of seeds is determined, among others, by the ratio of their weight to cross-sectional area. Since empty and full Scots pine seeds do not differ significantly in dimensions (Tab. 1), there is a strong correlation between their critical transport velocity and weight. Thus, as observed also by TYLEK (1999), light impurities can be removed from the seed material using pneumatic separators, due to the absence of significant differences in seed dimensions and the fact that cleaning machines where seeds are separated based on weight are rarely used. It is important to set the proper air flow velocity because, according to SKRZYPCZYŃSKA and SKRZYSZEWSKI (2000), the percentages of empty seeds may differ considerably even in the material harvested in the same region. Another important consideration is the cost-effectiveness of seed pre-cleaning in a stream of air (SARNOWSKA, WIĘSIK 1998). This simple and efficient method is much cheaper that separation with the use of near-infrared radiation (850 to 2360 nm) and recording radiation that passes through or is reflected from seeds (TIGABU, ODÉN 2003), which requires advanced and expensive equipment and is less effective.

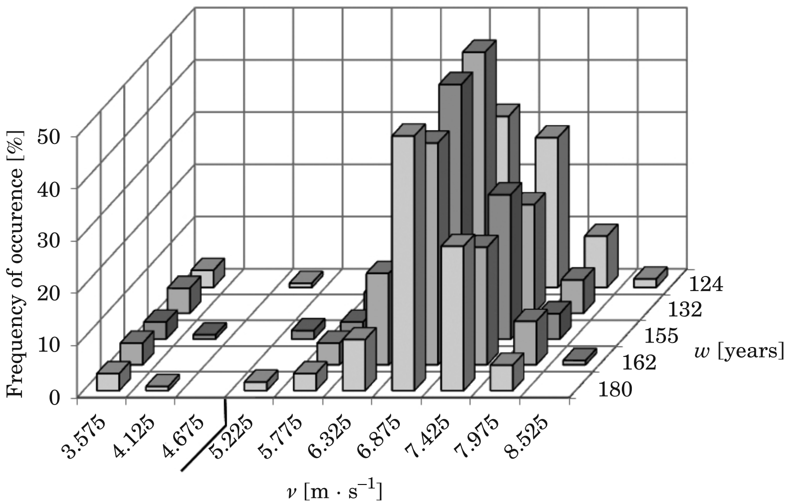

Fig. 1. Correlations between the critical transport velocity of seeds and the age of parent stands
Source: own study.

Table 1
A comparison of the average values of selected physical properties of seeds sorted based on critical transport velocity

Property	Limit of classification:	
	$v < 5$ m · s^{-1}	$v \geq 5$ m · s^{-1}
v	3.66^b	7.00^a
T	1.42^a	1.44^a
W	2.50^a	2.46^a
L	4.31^a	4.25^a
γ	35.4^a	30.0^b
m	2.04^b	5.89^a

$^{a,\ b}$ – different letters significant differences at the 0.05 level
Source: own calculations

Table 2 presents the statistical parameters of the physical attributes of seeds of different batches at the second stage of the experiment. The ranges of the dimensions and weight of Scots pine seeds collected from aging stands were as follows: thickness – from 0.99 to 1.89 mm, width – from 1.68 to 3.15 mm, length – from 3.30 to 5.28 mm, weight – from 3.4 to 10.4 mg. The above ranges are mostly consistent with those reported for selected tree stands in Poland (CZERNIK 1983, KALINIEWICZ et al. 2011, *Nasiennictwo*... 1995, TYLEK 1998)

Table 2

Statistical distribution of the physical properties of seeds

Marking of stand	Property	x_{min}	x_{max}	x	S	V_s
WDN-124	v	5.78	8.53	7.03	0.594	8.45
	T	0.99	1.89	1.47	0.171	11.61
	W	2.06	3.19	2.49	0.227	9.09
	L	3.63	5.24	4.41	0.381	8.64
	γ	19	41	29.8	4.471	15.00
	m	3.6	10.4	6.36	1.579	24.83
WDN-132	v	5.78	7.98	6.97	0.471	6.76
	T	1.15	1.72	1.46	0.115	7.84
	W	2.10	3.07	2.56	0.197	7.71
	L	3.48	5.28	4.33	0.346	8.00
	γ	21	39	29.9	4.216	14.12
	m	3.6	9.0	6.24	1.144	18.33
WDN-155	v	5.23	8.53	7.07	0.600	8.48
	T	1.09	1.72	1.43	0.158	11.05
	W	2.01	2.97	2.48	0.179	7.21
	L	3.45	5.15	4.21	0.301	7.15
	γ	20	47	28.3	4.731	16.73
	m	3.4	8.7	5.83	0.956	16.40
WDN-162	v	5.78	8.53	6.97	0.550	7.89
	T	1.10	1.74	1.44	0.135	9.35
	W	1.68	2.79	2.40	0.189	7.89
	L	3.30	4.81	4.14	0.311	7.52
	γ	21	47	29.5	4.642	15.74
	m	3.5	8.8	5.58	1.078	19.33
WDN-180	v	5.23	7.98	6.97	0.510	7.32
	T	1.10	1.68	1.41	0.111	7.85
	W	2.02	2.93	2.41	0.163	6.76
	L	3.42	5.00	4.18	0.375	8.98
	γ	23	42	32.4	4.644	14.32
	m	3.4	7.3	5.45	0.857	15.73

Source: own calculations.

where the following values were noted: thickness – from 0.99 to 1.96 mm, width – from 1.72 to 3.18 mm, length – from 2.82 to 5.71 mm, thousand seed weight – from 4.0 to 9.8 g. The dimensions and weight of seeds are affected by the habitat and soil type, the genetic traits of tree stands, geographical location, weather conditions during cone and seed development, and even cone location in the tree crown (ANISZEWSKA 2006, BODYŁ et al. 2007, CASTRO 1999, KLUCZYŃSKI 1992, *Nasiennictwo*... 1995, OLEKSYN et al. 2001, SEVIK et al. 2010, SIVACIOĞLU 2010, SIVACIOĞLU, AYAN 2008, TURNA, GÜNEY 2009). An analysis of the significance of differences between the average values of the physical parameters of seeds harvested from variously aged stands (Fig. 2) indicated that the dimensions, weight and angle of sliding friction of seeds were also

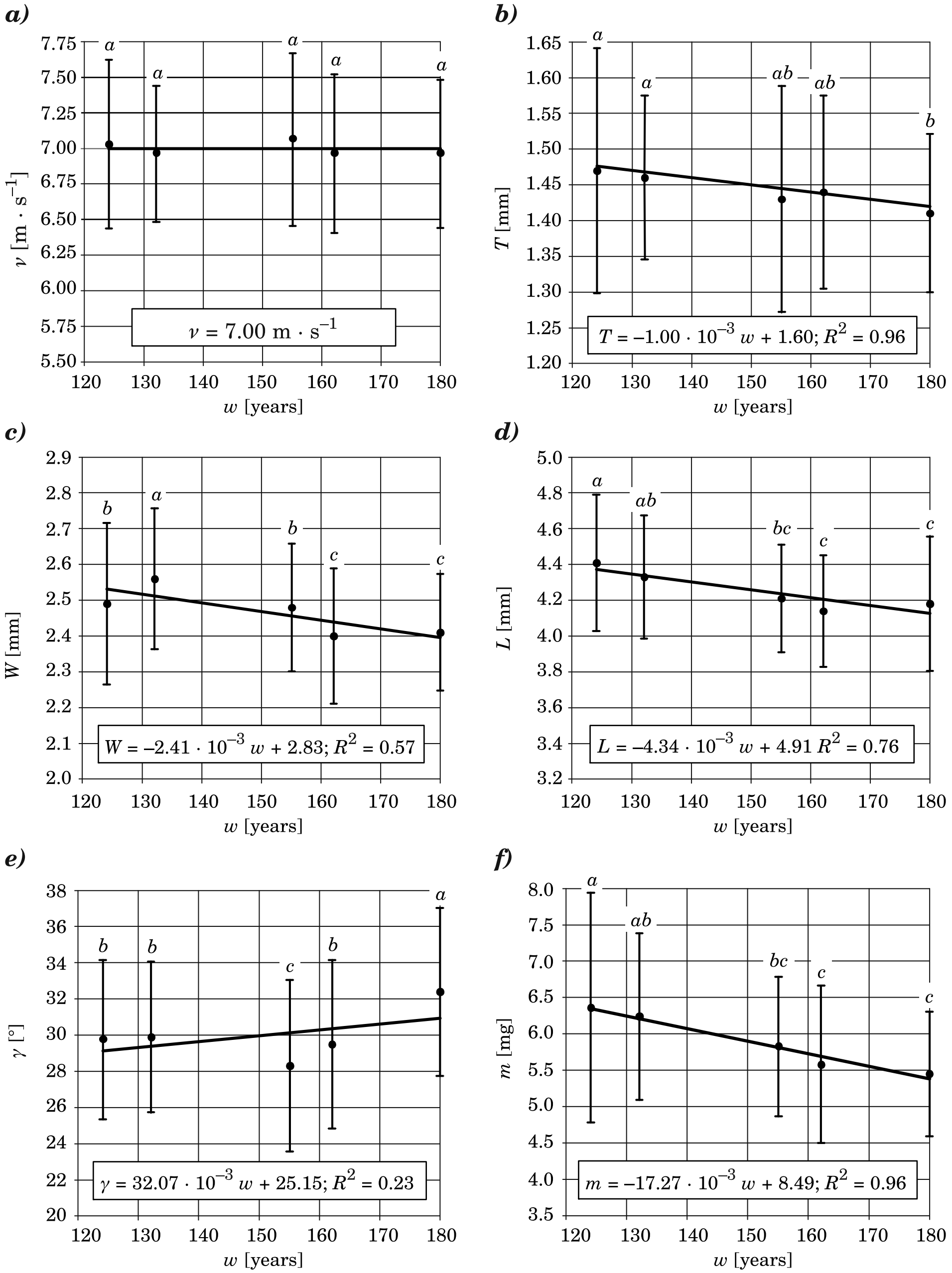

Fig. 2. The effect of the age of parent stands on the physical properties of Scots pine seeds: *a*) – critical transport velocity, *b*) – thickness, *c*) – width, *d*) – length, *e*) – angle of sliding friction, *f*) – weight; *a, b, c* – different letters denote significant differences at 0.05

Source: own study.

determined by the age of the parent stand. Statistically significant differences between seeds of different batches were not reported only with respect to the average values of critical transport velocity. It may be conclude that an increase in tree age is accompanied by a drop in the size and, consequently, the weight of seeds.

The coefficients of Pearson's linear correlation between the analyzed seed parameters (Tab. 3) showed that critical values were exceeded in 19 out of 21 cases. Correlations were not found between the age of the parent stand and the critical transport velocity of seeds, and between the angle of sliding friction and the length of seeds. The highest correlations were observed between the age of Scots pine stands and the weight, width and length of seeds. A strong correlation was also noted between the weight, critical transport velocity and dimensions of seeds. In the above cases, the values of correlation coefficients exceeded 0.5 and were considerably higher than the critical value of 0.08. Our results corroborate the findings of other authors regarding the seeds of Scots pine (BURACZYK 2010, CZERNIK 1983, SIVACIOĞLU 2010, TURNA, GÜNEY 2009) and other pine species (MATZIRIS 1997, SIVACIOĞLU, AYAN 2010).

Table 3

Coefficients of Pearson's linear correlation between the analyzed properties of seeds

Specification	w	v	T	W	L	γ	m
w	1	–0.019	–0.145	–0.245	–0.248	0.138	–0.293
v	–	1	0.597	0.285	0.121	–0.187	0.518
T	–	–	1	0.471	0.304	–0.239	0.727
W	–	–	–	1	0.444	–0.097	0.753
L	–	–	–	–	1	0.019	0.703
γ	–	–	–	–	–	1	–0.140
m	–	–	–	–	–	–	1

Critical value of the correlation coefficient at the 0.05 level – 0.081
Source: own calculations.

Equations describing the effect of the age of parent stands on selected physical attributes of Scots pine seeds are presented in Figure 2. The values of proportionality coefficients in the equations show that the weight and dimensions of seeds decreased, whereas the angle of sliding friction increased with the age of parent stands. The weight of seeds from a 180-year-old stand was by 15.2% lower than the weight of seeds from a stand aged 124 years, because the former are characterized by lower thickness, width and length – by 3.8, 5.3 and 5.6%, respectively.

Conclusions

1. The age of Scots pine parent stands (124 to 180 years) affected the weight, dimensions and the angle of sliding friction of seeds, but it had no influence on their critical transport velocity.

2. Seeds harvested from a 180-year-old stand were less plump that those collected from a stand aged 124 years; the differences in the average weight, length, width and thickness of seeds were ca. 15.2, 5.6, 5.3 and 3.8%, respectively. The range of changes in the dimensions of Scots pine seeds implies that the operating parameters of mesh sieves do not require adjustment.

3. Regardless of the age of old-growth stands, empty seeds can be separated from the seed material using pneumatic separators where the velocity of a vertical air stream in the aspiration channel reaches ca. $5 \text{ m} \cdot \text{s}^{-1}$.

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