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Effectiveness of the pneumatic separation of Norway spruce *Picea abies* (L.) Karst seeds

Abstract: The paper presents the theoretical basis for the pneumatic separation of Norway spruce seeds along with the results of investigations into the effectiveness of separation conducted in a pneumatic separator with a vertical air column. Such a separator was designed and produced at the Department of Forest Works Mechanization of the Agricultural University of Kraków. The device makes it possible to separate a mixture into three fractions based on the differences in critical velocities. The variation in density among different seed fractions is about two times lower than the variation in seed mass. This result supports the suggestion that omitting the size calibration of seeds before their pneumatic separation could lead to the dominance of seed density as a distinguishing feature.

Additional keywords: critical velocity, distinguishing features, seed sorting

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Introduction

The current annual demand for Norway spruce *Picea abies* (L.) Karst seed in Poland can be met at a level of 13% of the mast seed crop. This indicates that the seed deficit is not very serious despite the fact that mast crops in Norway spruce occur only once per three to five years on average. The important thing is to create seed reserves for years with very poor seed crops. The reserves should be made using seeds of the best genetic quality (Gozdalik 1995). This is especially important to the production of containerised seedlings. The seeds used for such kind of nursery production should be properly cleaned and sorted according to mass or size so that they have great viability, high germination capacity and high germination rate (Suszka 1999).

Most separation processes that use mechanical separators are based on the differences in several physical features of seeds, and in some cases also in the properties of trash particles. Due to the large number of distinguishing features it is possible to choose among them freely while elaborating the process of purification and segregation of seeds. Optimisation of that process requires choosing the features which make it possible to minimise the duration of processing (Grochowicz 1994).

Principles of the pneumatic separation of seeds

Pneumatic devices are widely used in the separation of the seeds of forest trees because they offer many advantages: simultaneous purification and sorting of seeds, no damage to seeds, no change in the physical and biological properties of seeds, continuous regulation of the parameters of separation, high efficiency associated with low dimensions and low energy demand, low level of noise, no air contamination (in the case of aspirators).

A set of aerodynamic features is described by three indices: the coefficient of resistance, fineness ratio and critical velocity (of flying). The latter parameter is the best representation of the aerodynamic properties of seeds and can be used as their distinguishing feature (Czernik 1983). The values of this parameter are affected by some secondary distinguishing features like density, shape and cross-sectional area (Omobuwajo et al. 1999). Critical velocity is the velocity of the vertical air stream which keeps seeds suspended in the air as a result of balancing their weight with the strength of the air stream (Grochowicz 1994). Critical velocity can be described by the equation:

$$v_K = \sqrt{\frac{gG}{kF\gamma}}$$

where:

v_k – critical velocity (m s^{-1}),

g – acceleration of gravity (m s^{-2}),

G – seed mass (kg),

k – dimensionless coefficient of aerodynamic resistance,

F – lifting surface of seed (m^2),

g – air density (kg m^{-3}).

The critical velocity of seeds depends on their mass (the greater the mass, the greater the critical velocity) and on the cross-sectional area perpendicular in a given moment of time to the direction of the air flow (the larger the area, the lower the velocity). No relationship between these characteristics and terminal velocity was found: heavier seeds are usually also larger, and thus have a larger lifting surface. On the other hand, there is a relationship between terminal velocity and the ratio of seed mass to average cross-sectional area (Tylek 1999). The cross-sectional area of a seed is also positively correlated with seed volume. Taking all that into account we can conclude that the pneumatic separation of seeds should be preceded by their size calibration aimed at standardising the lifting surface if we want to segregate various mass fractions of seeds. The lack of size calibration would result in the sorting of seeds into density fractions.

Separation in the air stream is employed not only in sophisticated pneumatic cleaning devices but also in simple devices used for the cleaning and segregation of seeds. By the direction of the air column, cleaning devices can be classified into vertical, diagonal and horizontal, and by the conditions of the air flow – into vacuum, overpressure and hybrid. Pneumatic devices with a vertical air column play a central role in the pneumatic segregation of granular mixtures (Grochowicz and Panasiewicz 1970).

The vertical air column ensures a very high quality of segregation when the material to be sorted is supplied in small amounts. This results from the fact that in such a column seeds move up and down many times, and they frequently collide with one another (Tylek 1998). At the same time, in vertical sorting channels the stream of air affects seeds more heavily and for a longer time. The seeds can be affected by the air stream from different sides, which is very advantageous for the efficiency of separation. Apart from the length of the sorting channel and the regularity of seed delivery, several other factors can influence the effectiveness of pneumatic separation. The most important of them are: the composition of the mixture (the amount and kind of trash particles), the difference in critical velocity between various parts of the mixture, and the homogeneity of the air stream (Grochowicz and Panasiewicz 1970).

Investigations into the effectiveness of the pneumatic separation of seeds

A prototype of the pneumatic separator with a vertical sorting channel was constructed at the Department of Forest Works Mechanization of the Agricultural University of Kraków (Tylek and Walczyk 2002). It is similar in design to a number of separators produced in Scandinavian countries and currently available in the market (Sarzyński 1994). The construction, however, is different in several aspects, which made it possible to patent the invention in Poland under the name of a "Pneumatic separator for loose materials, especially for forest tree seeds" (P-353630). The separator enables one to separate a mixture into three fractions based on the differences in critical velocities. The device was employed for the pneumatic separation of Norway spruce seeds. The seeds were collected in the Bukowiec Forest Management Unit, and had the germination capacity of 82% and moisture content of 7.1%.

At the beginning, from the lot of 1 kg of spruce seeds the fraction of light impurities was removed by setting the air flow velocity at 2 m s^{-1}. The measurement of air velocity with an accuracy of 0.02 m s^{-1} was performed by using a channel hot-wire anemometer Airflow TA5. The remaining portion of the mixture was sorted by dividing it into three parts. The air flow velocities in certain sectors of the channel were set in such a way that the total masses of the three seed fractions obtained were similar (see Table 1). From each of the fractions a sample of 135 seeds was taken and the mass of seeds and their density were determined. The measurements were conducted using analytic scales combined with a set designed for determining the density of various solids and liquids. The measurements of each seed were taken twice: first in the air, and then after submerging the seed in a liquid of known density (ethanol). The results of the measurements are shown in Table 1.

Table 1. Physical features of Norway spruce seeds after pneumatic separation

Item	Impurities*	Fraction I	Fraction II	Fraction III
Critical velocity (m s^{-1})	< 2.0	2.01–5.55	5.56–7.40	> 7.40
Fraction mass (g)	4.4	320.1	335.5	340.0
Seed mass				
average (mg)	–	5.1	9.5	10.2
coefficient of variation (%)	–	56.1	19.2	21.1
Seed density				
average (g cm^{-3})	–	0.56	0.89	1.08
coefficient of variation (%)	–	29.6	11.2	11.4

The average value of seed mass for fraction II was 86% greater than for fraction I, while the seeds in fraction III were on average only 7% heavier than those in fraction II. Comparison of the variations among the seed fractions with the t-test indicated that the difference between fraction II and fraction III was statistically insignificant at the 0.05 level. Similar comparison made for densities yielded differences of 59 and 21%; both of them were statistically significant. It is also worthy of notice that the variation in density among different seed fractions (expressed by the coefficient of variation) was about two times lower than the variation in seed mass. This result supports the suggestion that omitting size calibration before the pneumatic separation of seeds could lead to the dominance of seed density as a distinguishing feature.

The histograms in Figures 1 and 2 show the distribution of seeds among the mass and density classes obtained during the process of pneumatic segregation. Looking at seed mass (Fig. 1) one can see that the distributions of fractions are very flat-shaped, without clear maximum values. The distributions of fractions II and III are almost identical, and the seeds classified into fraction I represent all ten mass classes. In the case of density (Fig. 2) the distributions of fractions display clear maximum values, but again, it is difficult to establish the borders between fractions. The effectiveness of segregation, however, is definitely greater despite the fact that the difference between the seeds of highest and lowest density was at least 1.5 times smaller than the difference between the seeds of largest and smallest seed mass.

Conclusion

Theoretical analysis followed by laboratory tests indicated that the size calibration of Norway spruce seeds is of utmost importance to the course of the process of seed separation in the vertical air stream. Depending on the expected use of seeds (sowing in the open, point-sowing in the containerised production of seedlings, long-term seed storage) the need for calibration should be considered before planning the process of separation. It seems reasonable to determine the rate of seed feeding into the pneumatic separator (separator's efficiency) because it could substantially affect the effectiveness of separation. The loading per unit area of the working channel, estimated by various authors, should be treated as a starting point for conducting empirical tests, but has no direct practical significance.

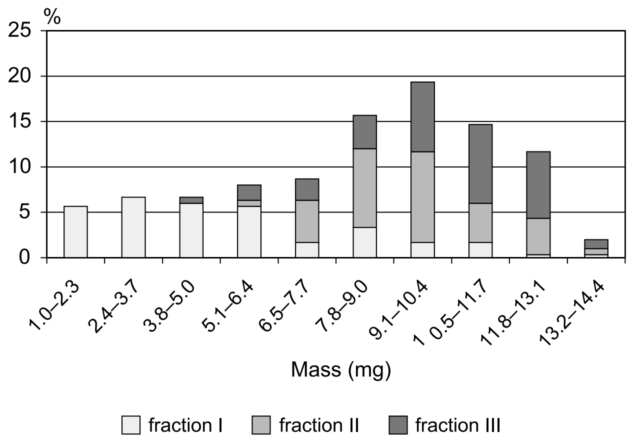

Fig. 1. Distribution of various fractions of spruce seeds into seed mass classes

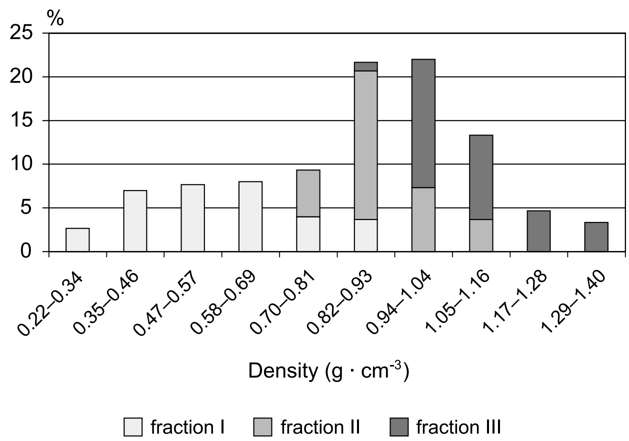

Fig. 2. Distribution of various fractions of spruce seeds into seed density classes

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