The features designed of mechatronic system of adaptive hopper's feeder: case study for Scots pine seeds morphometry

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Abstract. This article will be of interest to engineers involved in designing devices for improving the quality of forest seeds. From the point of view of automated processing, in order to obtain a quality seedling, the seed of the Scots pine must be conditioned, that is, properly graded, and have sufficient ability to germinate in the field, that is, properly sown. It is based on studies of the movement of a single pine seed in the mechanical system of an optoelectronic separator. The experiment was established by measuring the geometric dimensions of samples (n = 500) from a representative sample of a seedlot. The Pinus sylvestris L. seeds were collected in the Pavlovsky district of the Voronezh region in autumn 2019. Seed samples were measured using a microscope in three mutually perpendicular directions. Seed samples asymmetric shape and an adaptive hopper's feeder were modeled using SolidWorks software. Our results point to an important feature in the design of loading bins-the need to approximate the complex shape of a single seed of Scots pine with an asymmetric ellipsoid. The need for discrete seed feeding with a frequency no faster than $10^{-3}$-$10^{-2}$ s is established to improve both the separation process.

1. Introduction

The selection of forest tree seeds with the expected biological characteristics is done using their correlations with physical properties [1]. Those properties, called distribution features, include first of all: geometric features, density, aerodynamic features, friction coefficient, surface texture, and increasingly electrical and spectrometric properties [2]. The latter spectrometric features are used for the selection of pine species [3, 4], fir species [5], oak species [6] seeds etc. They are important for assessing the seeds viability, but for effective accurate operation of feeders, the determining factor is the uniformity of the seeds geometric shape. There are studies of the process of sorting pine seeds by size [7] before direct seeding [8, 9]. Seed morphometry can affect changes in the quality of forest reproductive material [10]. There are studies of seedlings growth at the juvenile stage from the Scots pine seeds sorted by size [11].

The implementation of the above methods for improving forest reproductive material requires careful modeling and design of technical means at the initial stage. This kind of knowledge is further required when designing and building various sub-assemblies of machinery and equipment used in improving seed material, in operating effectively seed cleaners and mechanical seed sorters as well as other machinery used in seed processing. Both contemporary and older designs of separators utilize
the experience of practitioners rather than the theoretical concepts rooted in deep knowledge of physics properties of seeds. In view of the above, there is a necessity of a detailed analysis of separation-related properties of seeds, including the features not yet used in forestry, but which should be considered when designing future universal separators. From the point of view of automated processing, in order to obtain a quality seedling, the seed of the Scots pine must be conditioned, that is, properly separated, and have sufficient ability to germinate in the field, that is, properly sown. In modern sorter and seeder constructions [12, 13] designed on the basis of Voronezh State University of Forestry and Technologies named after G F Morozov (VSUFT) an important role is given to the seeds geometry when designing adaptive feeders.

Forest seeds are considered as an object of interaction with the working bodies of separating and seeding machines, and therefore a number of its features should be taken into account. Seeds are living organisms that should not lose their viability during processing. This imposes a number of restrictions on the working organs of the machines, which should not cause mechanical damage to the seeds and damage its internal structure (compression, high temperature, etc.).

The size and properties of forest seeds have a direct impact on the type and design of technical equipment. Based on the size of Scots pine forest seeds, it is classified as small seeds with a size from 3 to 6 mm. In addition, within the specified category and within a certain type of seeds can also be divided into small, medium and large, which is reflected in some parameters of the working bodies (for example, the size of the seed disk cells) and operating modes [14].

While designing mechatronic systems [15] of separating or seeding devices, the morphometry of forest seeds [16] is a necessary condition for assigning subsequent modes of its operation. Many scientists have done study on the shape and size of seeds, and various analytical reviews are presented [16–21]. The approximation of the shape of the Scots pine seed for solid-state modeling varies among different researchers. Novikov et al. [22] recommends simulating the shape of the seed with a ball, Kaliniewicz et al. [17] an ellipsoid, Keefe and Davis “as a sum of fused partial ellipsoids [19]”. However, most of the studies were conducted in relation to stationary laboratory equipment.

The aim of the paper is to study the following question: how to apply the obtained morphometric data of pine seeds a priori and simulate adaptive seed feeding with minimal mechanical impact on the seeds?

2. Methods and materials

The coniferous seeds have a variety of shapes and are therefore characterized by three sizes: length $l$ (largest size), width $b$, and thickness $h$ (smallest size). It can be modeled approximately by analogs of bodies that have a mathematical description or by its combinations. Geometric parameters may form a basis for the Scots pine seeds separation traits. The size of seeds, as their most important physical property has a particular significance in the evaluation of their viability and in the processes of cleaning, storage and sowing. In the separation processes the thickness is important when using sieves with longitudinal holes, and the width for sieves with circular holes. The surface areas of seeds affect their aerodynamic and ballistic properties [23]. However, the above basic geometric parameters do not provide knowledge about seed asymmetry and are insufficient in the seed shape modeling process.

In order to more accurately simulate the shape of the seed, in addition to its base size, it is necessary to determine the location of the largest cross-section of the seed within its length. If the largest cross-section is placed asymmetrically along the length of the seed, then the seeds correspond to the shape of an asymmetric ellipsoid of rotation or the shape of an asymmetric ellipsoid.

To determine the location of the largest cross-section of the seed along its length, appropriate measurements were made for a batch of Scots pine seeds. The study was carried out on samples from a seed batch originating from the Pavlovsky district of the Voronezh region. The seed was collected in autumn 2019. According to the standard seed-processing protocol [24] seeds were de-winged in a drum-type wet de-winger (Dewing 800–BCC AB, Sweden), and then dried in a chamber (DL1200–BCC AB, Sweden) on a moisture level of 7.0 %. Empty seeds were eliminated using Gravity separator (Mini-Series—BCC AB, Sweden). Seeds in terms of seed quality corresponded to class II, the weight
of 1000 seeds were 8.3 g for pine seeds. The humidity determined according to Government standard in Russian Federation [25] corresponded to the warehouse and was 6.7-7%. The seeds were stored until the time of the study in February 2020 in a dark room in tightly sealed glass containers at a temperature of +5 °C and a humidity of 5%. Just before the experiment, the seeds were kept in the laboratory for 24 h at a temperature of 20 °C and 40% air humidity. During the study, we used the eScope iTEZ digital instrument USB microscope with a magnification range from 10 to 200 times, a 9-megapixel sensor resolution, and a led backlight (figure 1a).

**Figure 1.** Measuring equipment used for the study of the morphometry of the Scots pine seed samples: (a) USB microscope; (b) digital caliper; (c) measurement process.

Additional selective contact control of seed parameters and its installation in different projections was carried out using a digital caliper (figure 1a). The contactless method did not deform the seeds during the measurement. During the measurements, the seeds were divided into 20 groups of sets of 25 samples each. The measurements were carried out with an accuracy of 0.1 mm, the maximum error did not exceed 0.05 mm, and were similar to the errors obtained during the research using optical methods.

The classic image analysis was used to convert the characteristic sizes of the Scots pine seed along three axes (figure 2) [26]. In software Image Tools 3.0 (UTHSCSA, San Antonio, USA), you set the scale, specify the start and end points of the seed diameter, and convert the pixel distance between the points to millimeters. 3D modeling of the seed and the mechatronic system of the optoelectronic separator was performed using the SolidWorks software.

**Figure 2.** Seed measurement circuit.
3. Results and discussion
The results of measuring the distance $l_2$ (figure 2) from the pointed end to the largest cross-section of the seed are shown in figure 3a. $Y$-axis delayed values of the $l_2$ to the length $l$ of the seed, and on the $X$ – axis is the frequency relative to the center of the graph, expressed as a percentage.

The measurement results of the distance $h_1$ from the lower part to the largest cross section of the seed shown in figure 3b. On the $X$ axis ratios of $h_1$ to the $h$ ($h_1/h$), and the $Y$ – axis is the frequency, expressed as a percentage. A seed sample is fixed between the caliper jaws, and the average measured seed sizes are shown in figure 3c.

![Graph of displacement of the largest cross-section of seeds in length (a), in height (b) and the general appearance of the seeds (c) with characteristic average size values.](image_url)
As follows from figure 3a, the distance to the largest cross-section of the Scots pine seeds varies significantly (0.45-0.85). In this case, the distribution curve has a pronounced extremum, and the frequency of occurrence of the largest cross-section at a ratio of 0.64-0.66 reaches 45%.

As follows from figure 3b, the distance to the largest cross-section of Scots pine seeds differs significantly (0.35-0.75). In this case, the distribution curve has a pronounced extremum, and the frequency of occurrence of the largest cross-section at a ratio of 0.54-0.56 reaches 49%.

Therefore, the seeds of the Scots pine tree correspond to the shape of an asymmetric ellipsoid with average values of length $l = 4.82$ mm, width $b = 2.95$ mm and thickness $h = 1.96$ mm. Based on the obtained dimensional characteristics of the seeds, its three projections were created in the SolidWorks 3D CAD environment, shown in figure 4. The spline style tool was used to get the most approximate parameters of the created contours. (figure 4a). A parametric solid model of the seed was created from the constructed spline contours (figure 4b).

Figure 4. General view of the asymmetric model of the Scots pine seed: (a) spline model; (b) parametric model.
In this case, all projections have the ability to introduce asymmetry. So, for pine seeds, the upper and front planes have mirror symmetry. The side projection is completely asymmetric.

It should be noted that the weight of 1000 seeds were higher than in the case of seeds tested in Poland. Here it was 5.5-7.4 g for class II, depending on the harvesting microregion. The analyzed seeds were similar than the material originating from southern Europe [27]. Similar trends were noticed with regard to the linear dimensions of the seeds. In turn, some differences were noted in the proportions of dimensions: length, width, and thickness. Based on the analysis of the sphericity coefficients, it was found that for the tested seeds they reached slightly higher values. The seeds analyzed by other authors were slightly slender.

It should be considered that the smallest seeds are generally characterized by the lowest germination capacity. They are removed together with impurities [1]. For this reason, seeds should be divided into fractions. The basis should be considered on a trait that promotes even seedling development and prevents seedling dominance [28]. It is often the seed mass, therefore, physical parameters that are strongly correlated with seed mass have to be taken into account when designing the process or technical systems for seed separation and sorting. It should be noted, that seedlings developing from only one fraction must not be supplied for forest renewal because such a practice could contribute to the narrowing of genetic diversity. Moreover, seeds obtained from old trees and stands are usually smaller.

The parameters of the asymmetric model of the Scots pine seed were visualized using the example of a 3D model of the separating device presented on figure 5.

![Figure 5](image-url)

Figure 5. General view of the solid-state functional model of the separation device according to RU patent 2 682 854 [12], taking into account the morphology of the Scots Pine seeds.
In figure 6 the general view of the solid-state functional model of adaptive hopper’s feeder is additionally presented.

![Figure 6](image_url)

**Figure 6.** General view of the solid-state functional model of adaptive hopper’s feeder.

Thus, the functional models presented in figure 3 are adjusted taking into account the asymmetric morphology of Scots pine seeds and allow increasing the accuracy of a priori modeling. For an optical sorting device, it is very important to feed the seed one at a time at intervals no faster than $10^{-3}$ s. Moreover, it is also important to know the position of the seed at the time of identification by the optical beam. This position is determined by the location of the center of gravity of the seed and its fall trajectory in the seed duct of the optical sorter. When changing the size of pine seeds in the direction of decreasing and increasing, this will not affect the overall height of the optical module of the sorter in any way, since for seeds of 4-6 mm in size, it depends only on the time of their movement in the vertical seed tube.

### 4. Conclusion

The results of the presented study indicate a significant asymmetry in the location of the largest cross-section of the Scots pine seed along the length and height of the seed. This indicates that it is necessary to correct the size and shape of pine seeds while modeling separation and seeding processes. Further study should use a more holistic approach to this issue by examining the morphological features of asymmetry in seeds of different years and places of collection. Also, due to the significant variation in the asymmetry values, it is necessary to consider a stochastic model of separation and seeding.

A detailed study of the seed shape will also allow you to create more reliable numerical simulation models of seeding apparatuses, separators and seed draggers using 3D-CAD and CAE applications.
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