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Mechanization of coniferous seeds grading in Russia: a selected literature analysis

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Abstract. The review is intended for international readers or those unable to read Russian. The review is based on long-term research of the affiliated University and search in Russian-language databases. Currently, there is a large number of sites in the Russian forests that need to be restored. Mechanization of grading seeds in Russia has more than half a century of history. The results of retrospective analysis show that the choice of the sorting method depends on the seed characteristics and the level of achieved technologies in equipment design. The prospects for the use of optoelectronic and mechatronic devices for such purposes are due to low costs and negative impact compared to the use of grid and trier. The research materials will allow planning new experiments to find a reliable protocol for testing and preparing coniferous seeds, depending on the method of further seeding or storage. The study will allow to correct plant propagation protocols for sustainable forest management. However, many questions remained unresolved: what types of grader and pelleting apparatus to use, what wavelength range is best used to identify viable seeds?

1. Introduction

Forests form the ecological framework of our planet, performing protective, water protection, climate control, biosphere, air purification and other important functions. The increase in forest cover and expansion of the functions of the reforestation are an important measure of oxygen production and carbon sequestration in forest ecosystems [1], as well as environmental protection [2], food and social security [3] under sustainable management [4] using information systems [5,6]. According to the Food and Agriculture Organization of the United Nations (FAO), the world's total forest area changed from 4 billion hectares in 1946 to 4,033 billion hectares in 2010 [2]. At the same time coniferous forests occupy about 15 % of the territory [2].

Logging of phenotypically superior individuals of the region's commercial species removes the best genotypes from a population, leaving the poorest individuals of the least profitable species to produce seed to regenerate future generations [7]. This process of dysgenic selection will exacerbate the other problems of genetic drift, inbreeding depression and reduced genetic diversity that may arise from reduced census number [8]. An important place in the reforestation is occupied by seeds [9, 10]. "Good seed handling is an essential complement to genetic improvement [11]". The importance of seeds grading [12, 13] is necessary both for obtaining viable seeds [14] and for increasing the efficiency of seeding apparatus [15, 16], including aerial seeding [17, 18].

The spectrum of phens [19,20], consisting of qualitative and quantitative morphological parameters can be used as grading criteria. Features of Scots pine species, which were widely used by seed grading mechanization, are divided into two main groups: quantitative and qualitative (marked in table 1 in italics).

Table 1. Phenotypic structure of Scots pine species [19, 20].

Qualitative feature	Quantitative feature
Color of needles (dark green, green, yellowish-green, greenish-yellow, bluish-green); color of bark (pale reddish-brown, tobacco-brown, Golden-yellow, yellow, pale yellow, blood-red); color of Mature cones (dark smoky, green-gray, brown, reddish, dark gray, honey-yellow, greenish-gray, green-malachite, green, ochre)	Height, diameter, trunk volume and total biomass of the tree, height of rough crust uplift, bark thickness, number of branches in the whorl, needles length (short, "normal" and long);
Color of female inflorescences (blood red, grass green, chestnut, olive green)	Degree of needles density on shoots (dense, medium and sparse), the number of cones in the whorl (including bunch-cones)
Color of the anthers (yellow, orange-red)	Length, width and weight of cones
Color of the wing (terracotta, brown, pale terracotta)	
Seed coat color (black, brown, pale gray, ash gray, white etc.)	
The structure of the crust (scaly, lamellar, scaly-lamellar, lamellar-scaly)	
Form of Apophis cones (flat, lumpy, crooked); Litter of pine needles (second and third years of life)	Seed size, weight 1000 pieces, specific gravity
Periodicity of reproduction (every year, 1, 2, 3, etc., generally lean)	
Architectonics of the crown (ovoid, conical, plausible, fusiform, and globular)	

However, little information about coniferous seeds grading mechanization and its future development in Russia is available to international readers or those unable to read Russian. The purpose of the study is to answer the following questions. What are the frontier engineering impacts of different mechanization methods in Russian? Can we develop a reliable protocols for seed grading mechanization based on phenotypic characteristics?

The search by the keywords "seed grading & forestry", "seed sorting & forestry" was carried out in the English-language databases WoS, Scopus, CABI. Further, the authors selected the most relevant documents for analysis. Information search was carried out on the keywords "forest seed & sorting OR separation" in the Russian-language databases ELibrary. It was found that there is no electronic archive from 1928 to 2015 of the largest forest journal of Russia "Forestry" (ISSN 0024-1113). Therefore, the hard copies of this journal were viewed in the scientific library of Voronezh State University of Forestry and Technologies named after G.F. Morozov.

2. Seed grading mechanization

Coniferous seed processing mechanized by equipment presented in table 2 and consists of nine technological operations. Each of these operations has a certain level of mechanization. Basic operations 1 to 5 is carried out after harvest of the seed, using the appropriate equipment. Until recently, the most damaging operation of seeds was exfoliation, which used brush and grating working parts. However, the discovery of the effect of a liquid desiccant using a drum device similar in design to a dragger increased the energy efficiency of the operation. After that, the most negative operation affecting the seeds is the 6 – grading operation. When it is performed, the seeds directly interact with the working parts of the devices, which have a destructive effect, mainly of a mechanical nature. This is especially true for devices that use sieves and sieves, in which up to 15-20% of valuable seeds may be lost. All devices with direct interaction of working parts with seeds are used as a quantitative separation criterion (seed size, weight 1000 pieces, specific gravity, etc.).

Table 2. Coniferous seed processing.

	Processes	Equipment	Reference
1.	Precleaned &	Precleaner	[21]
	Precured (dried)	Cone-Dryer	[22, 23]
2.	Extracted	Extractor	[21]
3.	Dewinged (de-winged)	Dewinger	[24]
		Debearder	[23, 25]
4.	1st Cleaned	Scalper	[23, 26]
		Pre-cleaner	[23,27]
5.	2nd Cleaned	Air-screen cleaner	[22, 24]
		Disc separator	[28, 29]
		Belt Cleaner	[30]
6.	Graded	Grader	[31]
	6.1. Size (*quantity*)	Length separator	[31]
		Vertical rotating-screen separator	[32]
	6.2. Gravity (*quantity)*	Specific gravity separator	[31, 33]
	6.3. Density (*quantity*)	Air separator OR Aspirator OR Pneumatic separator	[12, 34]
	6.4. Frictional (*quantity*)	Spiral separator	[24, 27]
		Inclined draper	[27,31]
	6.5. Magnetic (*quantity*)	Magnetic separator	[23,35]
	6.6. *Optical (quality features*)	*Optical sorter*	[36, 37]
7.	Treated	Treater	[22, 23]
		Dresser	[38]
8.	Adjustment of moisture content	Dryer	[21]
9.	Packaged	Bagger-weigher	[23]

With the development of optoelectronic technologies, it became possible to use a qualitative criterion for seed separation – their spectrometric properties, which reflect the degree of viability and germination. At the same time, in the detecting system of optoelectronic devices, it is possible to achieve complete absence of mechanical interaction with the seed when performing grading operations. Operations 7-9 are the final operations of production, the execution of which must meet the goals of further use of seeds – for storage, for cryofreezing, for seeding (ground or aerial seeding), etc. Depending on the purpose of the seeds, the technological modes of operation of the devices used in operation 6 – grading operation are selected. It is obvious that the quality of seeds when grading directly depends on the technical means used.. Meanwhile, the seeds quality is understood as follow.

2.1. Seed quality

The term "seed quality" is used in agriculture to describe the overall meaning of seed a lot for its intended purpose [39] and includes mass, conservation, germination energy, and field germination. According to [40], "as we are still dealing with wild population in forestry, the genetic quality of tree seed has to be determined by provenance research and certified at source". Generally, seed quality is determined by the heredity and environmental conditions of the parent plant during seed development [40, 41]. It is well known that seed germination and viability can vary greatly from year to year and from one place of production to another [39]. In Canada, for example, 4.1 billion seeds were used in 1970, with genetically improved seeds accounting for less than 1%, and 7.3 billion seeds by 1987, with 3% of genetically improved seeds [42].

Moreover, the "variation in seed quality among cultivars in response to increasing growth temperature detected in our study suggests that selection of new cultivars is a key way to cope with loss of seed quality in response to increased global warming" [43]. Evaluation of quality indicators (germination, viability, humidity, purity etc.) is provided when seeds testing [38, 44]. Forest seed grading on a given basis has a definite and ambiguous effect on germination and viability [40].

On the one hand, separation leads to the elimination of quite viable seeds of small fractions. This process can change the genetic structure of the seed lots, by discarding the whole family [12,33]. Some authors consider it necessary "the filled-viable seeds from all size classes should be mixed prior to placing the seed- lot in cold storage or, if not stored, prior to the seeds being sown [45]".

On the other hand, there were no statistically significant differences in the level of genetic diversity between the native spruce forest, a derived forest stand formed from the surviving undergrowth, and forest crops created by direct seeding [46].

Comparing the size of seeds not within the species, but between species, we can conclude, "that only large seeded species, such as oak, should be used for forest restoration of abandoned fields by direct seeding [47]". The main purpose of harvesting seed production in forestry is to obtain "the maximum possible number of environmentally friendly seeds with high viability [48]".

To select the means of mechanization used in operation 6 (see table 2), it is necessary to consider the effects of engineering effects of working bodies on seeds and subsequent forestry effects of seedling growth. Consider the effect of mechanization when grading coniferous seeds by quantitative and qualitative criteria – *Seed grading quantity effect* and *Seed grading quality effect*.

2.2. Seed grading quantity effect

One of the methods of solving the problem of reforestation is the cultivation of enlarged planting material in nurseries without overshooting. The implementation of this technology makes the presence of aligned seed by size a prerequisite. Sorting is an integral operation of the coniferous seed technology.

In retrospective studies [49, 50] the size and density were taken as the main signs of grading, which could fully realize the point sowing of seeds in nurseries [33].

Sowing quality of seeds can be significantly improved by applying after separation on sieves separation of their density, increasing the germination of soil seeds of forest crops [51].

In forestry practice, there is a wide variability of trends on the impact of the size (mass) of forest seeds on sowing qualities. Here are the most common [28]:

– larger seeds produce larger seedlings than smaller ones. The use of unsorted seeds for crops leads to culling of 20-25% of non-standard seedlings when they are grown in the nursery [52, 53];

– the size of the seed affects the plant up to a certain point;

– there is an inverse correlation between size and germination;

– no dependence between seed size and germination.

The issue of the expediency of separation of forest seeds on a quantitative basis is also characterized by ambiguity of opinions. According to Turnbull (1975), the differentiation of healthy seeds depends on "(1) the degree of difference which exists between the seeds and the matter to be separated from them and (2) the degree of uniformity among the seeds themselves [54]".

One group of researchers [55, 56] showed that there is a need to separate seeds by size and weight (density) to ensure the effective cultivation of planting material in nurseries. Moreover, many of them proved that it is possible to effectively use all the seeds, both heavy and light, carrying out differentiated seeding taking into account the depth of seeding and seeding rate.

Papers [57,58] studying the individual properties of pine and spruce seeds, came to the conclusion that in order to obtain high-quality seed material, they must be cleaned of impurities and divided into certain fractions using vertical air flow. They argue that the seeds of large fractions have better germination and vigor. A similar view was expressed [59], which proved that the seed mass after purification should be sorted into fractions by specific and absolute weight. Novoseltseva [60] considered it appropriate to sort the seeds by size, as large seeds have a greater supply of nutrients and, accordingly, greater soil germination and growth energy.

Another group of scientists [61, 62] argues that the expediency of separation of the seeds could not be clearly substantiated in any biometric parameters (length, width and thickness of the seed) separately and has no sustainable effect on germination, since the achievement of these parameters is not a sufficient indication of biological maturity of the seed. Girgidov and Gusev [61] found that uncalibrated seeds had higher soil germination than calibrated ones, with differentiated seeding rates and therefore calibration by size is not justified. It should be taken into account that the calibration of seeds was carried out only on the size characteristics without taking into account their density, so all fractions could have seeds empty and underdeveloped.

It should be noted an important fact: the question of the organization of seed economy of the Russian Federation, which was raised in the late XIX-early XX centuries, was largely implemented in life by well-known scientists and foresters [63,64]. In 1950-1960, it was believed that sowing of large and small seeds was due to their rational use: by reducing the seeding rate and producing differentiated seeding, it is possible to significantly increase the yield of standard planting material from the same number of seeds.

In general, it can be reasonably argued that by dividing the seeds into several sorted fractions and seeding them into the soil separately at different depths at certain seeding rates, it is possible to increase not only the soil germination. Seeding of small and large seeds, separated by density, makes it possible to change the duration of cultivation of the planting material, since larger seeds produce larger seedlings that can be dug earlier. Crops from small seeds remain at the same time for rearing. Ultimately, with the appropriate sowing of seeds, it is possible to implement the technology of growing planting material without overshooting, which will make it possible not only to increase the yield of standard planting material per unit area, but also to reduce almost twice the labor costs, and save valuable seed stock.

Therefore, sizing seeds by size and further sorting them by density are important technological operations in the preparation of coniferous seeds for sowing. They eliminate the heterogeneity of the seed, increase the germination capacity and yield of the planting material per unit area. The lack of sorting technology and especially the calibration of seeds, as well as appropriate means of mechanization, greatly complicates the solution of this issue.

On a quantitative basis, depending on the method of influence on the subject, the following technologies for cleaning and sorting seeds are distinguished: mechanical (sieve, grate-free), air, liquid, electromagnetic, friction and combined. They are built on certain knowledge about the properties of the seed material and the signs of its divisibility: aerodynamic properties, density (specific weight), geometric parameters, electrical conductivity, surface properties, etc.

1) Technology for cleaning and sorting seeds on sieve devices

The technology of cleaning and sorting seeds on sieve devices uses the principle of separation by size characteristics-thickness and width – and consists in their sieving through oblong, round or square holes of sieves, performing reciprocating motion. This technology provides cleaning of seeds from large and small impurities, as well as separation of seeds into several fractions. In particular, it was found that in order to obtain a better planting material, it is necessary to divide the forest seed mixture into four fractions aligned in size and weight of 1000 seeds.

2) Pneumatic seed cleaning and sorting technology

The basis of the pneumatic technology of cleaning and sorting is the technological sign of the separation of the forest seed material by aerodynamic properties (windage coefficient, critical speed, etc.) using vertical, inclined and horizontal air flows. The effectiveness of this technology is due to the lack of seed injury, ease of adjustment of the working process. At the same time, the use of horizontal and inclined air flow leads to the fact that a significant mass of normally developed seeds gets into the waste. The use of vertical air flow can significantly reduce the loss of complete seed. However, the division into fractions by aerodynamic properties is associated with the use of special devices and additional losses of working time. The main disadvantage of the pneumatic method is that when using it, it is impossible to clearly divide the seeds into fractions by linear dimensions, as a result of which the seeding quality of the seed material is significantly reduced.

3) Technology of cleaning and sorting seeds on trier devices

The technology of cleaning and sorting seeds on trier devices is widely used in agriculture. This technology uses the principle of separation of seed material along the length and consists in placing shorter seeds in the cells of the hollow rotating cylinder and then lifting them and separating them into a trough located inside the cylinder. This technology provides within one Trier device division of seeds into two fractions – short and long-or allocation from seeds of the weed impurity coinciding on width and thickness, but differing in length.

Taking into account the features of hard-to-separate long impurities (needles) found in the forest seed material, it should be noted that the process of cleaning and sorting of the latter on Trier devices is impractical due to their inability to forestry, large dimensions and material intensity.

4) Technology of cleaning and sorting seeds on roller devices

The essence of the technology of cleaning and sorting of seeds on roller devices is that the seeds sorted by thickness are moved in the space between two inclined rollers with a slit size from the minimum size in the feeding zone (the beginning of the separation) to the maximum in the zone of their final separation. For its implementation Voronezh State University of Forestry and Technologies (VSUFT, Russia) developed and manufactured a number of designs of experimental samples of mesh-free separators, a distinctive feature of that it does not use sieve as a working body, but two polished rollers (smooth, stepped or combined), rotating at high frequency in opposite directions. Here, the separation of the thickness of the seed mixture into any number of fractions in the absence of jamming of seeds, as well as the allocation of small impurities.

5) Liquid technology of seed cleaning and sorting

Liquid technology is based on the principle of flotation, characterized by the ability of seeds to float or sink, depending on their density, in various liquids (water, alcohol, acetone, gasoline, salt solutions of different concentrations, etc.). In this case, empty and damaged seeds float to the surface, and full-grain, living, the most valuable in biological terms seeds sink.

However, in seeds that have been immersed in the liquid, during storage, germination rates may decrease. At the same time, for drying seeds to warehouse humidity, it is necessary to have drying chambers, the operation of which significantly increases the cost of seed material. Currently, the effect of technical fluids on the processes occurring in the seeds, insufficiently studied. Therefore, this technology is not yet widely used in sorting forest seeds.

6) Separation of seeds by electrical conductivity

The separation of seeds by electrical conductivity is carried out with the help of an electrostatic drum separator, the principle of which is based on the fact that the seed mixture is fed to an electrically charged rotating drum. Seeds with a small dielectric constant are attracted to the drum and removed from it with a brush, and the seeds conducting an electric current are freely discharged from the drum. A higher quality of separation of the seed mixture is achieved in corona electric separators, in which separation occurs in the electric field of the corona discharge.

7) Combined technologies of seed cleaning and sorting

Combined technologies of seed cleaning and sorting are widely used in forestry and agriculture. A distinctive feature of these technologies is the simultaneous impact on the seed material of different working environments: air, mechanical, liquid, etc.

2.3. Seed grading quality effect

The seed coat color is the most important indicator of the sowing qualities of seeds. It characterizes the degree of completion of physiological processes of seed maturation and genetic variability [12, 65].

Ability to diagnose seeds by spectral-optical criteria [66, 67], allows us to identify correlations for the prediction of germination [68] and viability [69], contaminants [70].

The greatest effect between the color classes is achieved by using radiation in the wavelength range corresponding in the near-infrared wavelengths.

Near-Infrared Reflectance Spectroscopy (NIRS) requires "minimal sample preparation, allows simultaneous analysis of several constituents, is nondestructive to the sample, and is fast (0.5 to 3 min/sample) [71]".

However, reflection spectroscopy is characterized by the highest level of "noise" when taking measurements.

In most cases, a single color trait, determined individually for each seed species, is a consequence of pathogenic changes [69]. In the remaining cases, there is a strong correlation between seed coat color and viability [69], obtained by tetrazolium assay [72].

The ability to remove the spectral characteristics of coniferous seeds and identify their degree of hydration [73] may lead to new ways to predict sowing qualities due to the existence of a correlation between germination and water content in seeds [74].

Conclusion

Mechanization of softwood seed sorting in Russia has more than half a century of history, rather broad theoretical study and practical implementation. Choice of engineering impacts on seeds during grading depends on the quantitative or qualitative criteria for sorting seeds and the level of efficiency of the achieved technologies in the design of equipment at a given time.

Proposed to make changes to the seed preparation protocol before seeding, which will allow to adjust the plant propagation protocols for sustainable forest management. It is necessary to use a qualitative grading criterion - spectrometric properties. Next, it is necessary to pelletize viable seeds and then grading the size of capsules to reduce the seeding rate and improve the performance of siders. Prospects for using optoelectronic grading devices are due to low costs and low negative impact compared to the use of devices with direct impact of working bodies on seeds.

In this regard, joint research is planned, including a number of issues. Can the seed coat colour be used as marker in the analysis of the ontogenesis of Scots pine? What devices will ensure high-quality separation of seeds by colour? Will the spectrometric and morphometric seeds parameters and technological operating modes of equipment be synchronized in a FRM-database [75]? These and other issues will be considered and discussed in future studies.

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