New technology for encapsulating conditioned seeds to increase aerial seeding efficiency

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Abstract. Study refers to the field of forestry, in particular, to technologies that ensure the encapsulation of seeds for aerial sowing during reforestation in areas inaccessible or ineffective for ground mechanization. The existing approaches today have a number of significant disadvantages: increased injury to seeds and the impossibility of subsequent directive sowing; insufficient density of the capsule outer shell for aerial seeding, allowing only surface aerial seeding; high complexity and laboriousness of execution, which does not allow its implementation in the field. Based on a systematic and patent search, the existing technologies for producing capsules, including freezing seeds, have been analyzed. The result is developed and patented sequence of operations, the effectiveness of using which in aerial seeding is confirmed economically. Its advantages are simplicity, increasing the accuracy of aerial seeding by ensuring the aerodynamic stability of the capsules in flight and increasing the protection of seeds in contact with the soil by placing the seeds inside the capsules. However, a number of questions remain for future research: how does the drop height and soil condition affect the strength and proportions of the capsules? How does the physical-chemical composition solution on the strength and proportions of capsules?

1. Introduction
To date, there are a number of scientific publications devoted to methods of encapsulating seeds [1-3] with various algorithms for their seeding [4-6], including aerial seeding [7-9]. The efficiency of aerial seeding can be increased by fulfilling the following conditions [10]: the use of unmanned aerial vehicles (UAV) with high-precision navigation systems [11] and aerial seeding [12] for the implementation of optimal flight schemes [13] for sowing seeds in different forest conditions; reduction of the ecological load on the environment [14] with simultaneous and subsequent monitoring of young forest stands [15]; the use of conditioned seed with specified quality indicators [16], obtained with the use of technical means separating viable seeds and forming seed capsules with the necessary physiological and physical and mechanical properties.

There are known technologies that provide such seed capsules during the restoration of forest landscapes, of which the following are distinguished. Seed preparation for aerial seeding [17], including treatment of seeds with an adhesive and mixing with sand (25-250 microns) on a vibrating table. The obvious disadvantage of this technology is the increased injury of seeds and the
impossibility of subsequent directive sowing due to the heterogeneity of the capsule sizes. Seed encapsulation [18], including obtaining capsules of coniferous seeds of a spherical shape, having an internal structure sufficient to ensure the flow of air and water into the seeds, and consisting of a composition of repellents, fungicides, organic substrate (substrate), agglutinating substances and fertilizers. This composition improves the viability of seeds in the resulting spherical capsules and is sufficient for use in reforestation. But the density of the outer shell of the capsules, too low for aerial seeding, makes it impossible to implement the method in the field. Presowing treatment of seeds of rare and relict plants [19], including packing seeds in paper bags, freezing them at a temperature of -51 to -30 °C for at least 35 days and a gradual increase in temperature to a low positive temperature (5-10) °C for 2-3 days, which makes it possible to increase vigor of germination and germination of seeds after long-term dry storage to obtain seedlings of high viability. Seed treatment [20] including: choice components and cooking composition certain concentration for pre-sowing processing seed, at storage supplemented inhibitor molds processes; processing seed composition from using systems soaking or spraying and subsequent encapsulation in smooth capsules spherical shape; storage seed at necessity; sowing seed any traditional way, different at superficial aerial seeding compulsory including on the first stage components for inhibition predation.

In given technology appears that one the same disadvantage, what and in previous - small density capsules, allowing realize only surface aerial seeding. The closest to the technology proposed in this article is the technology for preventing defective germination or plant growth [21], with which you can sow even the seeds of plants that are small in size. It includes the following stages: encapsulation of plant seeds into a water gel capsule, cooling of plant seeds and sowing the seeds itself. However, the high complexity and laboriousness of its execution does not allow the implementation of this technology in the field.

The generalized structural and functional analysis of all the above technologies makes it possible to establish their main drawback, which does not allow for efficient aerial sowing of high-quality seeds: the impossibility of forming capsules in the field that provide a solution to the dual problem - mechanical protection of seeds at aerial sowing speeds that guarantee the required depth of penetration into the soil, with simultaneous implementation of the technology of high survival rate of seeds and prevention of defective germination (growth) of the plant.

The study answers the following questions: how to improve the accuracy of aerial seeding of small and very light forest seeds by placing them in a capsule and changing the physical and mechanical characteristics of the capsule? How is it possible to obtain seed capsules at the lowest cost?

2. Methods and materials

The identification of trends in the development of the problem under study was based on the methods of conducting a systematic review and patent search with additions and improvements in relation to the current direction of research. The search was carried out in the databases of indexing systems (AGRICOLA, Forest Science Database, Google Scholar, Web of Science, Scopus), as well as international patent information databases (Lens.org and WIPO.org) using combinations of key terms: ‘Seed AND pelleting’, ‘seed AND encapsulate’, ‘seed AND bomb’, ‘seeding AND aerial’. The search was carried out not only by the titles of publications, but also by keywords and annotations in order to avoid an error of the first kind.

When developing the operations of the new technology, brainstorming methods and theories of inventive problem solving were applied. When analyzing the economic efficiency of the new technology, the authors proceeded from the fact that the process of encapsulating conditioned seeds is a link in the chain of the entire technological process of aerial seeding and cannot be determined in isolation from such stages as delivery of seeds and high-precision aerial seeding directly.

Revealed during the analysis of the requirements for a new technology of encapsulation of seeds, which ensures high efficiency of their seeding, make it possible to form the following distinctive features:

- low cost
the possibility of implementation in the field;  
high percentage of seed germination;  
the possibility of sowing on stony and sandy soils;  
low percentage of seed losses during aerial seeding.

It should be noted that an integrated approach to the consideration of the above features and main characteristics made it possible to form an integral and technologically consistent set of production operations and, in many respects, a new, in our opinion, technology for encapsulating elite seeds, which is described in detail below.

The technical device itself was designed and developed in the AUTOCAD computer-aided design system, with the help of which a 3D model was built, as well as drawings were created and executed. To implement a common environment for creating design documentation, the ZWCAD + add-on was used. It generated drawing elements using task-specific blocks and specifications. At the same time, full integration of data into a standard format was carried out, which made it possible to successfully use the layouts for related specialists.

3. Results and discussion

As a result of studying patent information and literary sources on the subject under consideration, a list of documents was formed, which in one way or another confirmed the correctness of the experimental laboratory or production characteristics of the capsules being formed. The most up-to-date information from this list is given in the introduction. At the same time, it was concluded that the use of immersion freezing is the most suitable for obtaining capsules in the field.

3.1. How to increase the accuracy of aerial seeding of small and very light forest seeds by placing them in a capsule and changing the physical and mechanical characteristics of the capsule?

The accuracy of aerial seeding is ensured by the accuracy of positioning of the aircraft, the accuracy and consistency of the feeding of the seeding apparatus with the speed of the UAV [12], as well as the aerodynamic stability of the capsule. The first two factors are separate studies outside the scope of this work. The extreme factor of ensuring accuracy is achievable by performing the following sequence of technological operations [22]:

- is created the form for placement capsules, containing given number N cells conical, arrow-shaped or etc shape, providing aerodynamic sustainability capsules given shape in flight (eg, bullet shape, shown in cut on the figure 1);

![Figure 1. Shape of aerodynamically stable capsules cameras and possible Form for their freezing (cross section along the Form connector line passing through the camera axis).](image)

- preparing solution, containing Ingredients, providing: effective germination seed (high probability germination, speed, sustainability to harmful factors and etc.); temperature freezing solution, appropriate temperature, optimal for storage and effective germination specific kind seed. In this case, in-first, provided location seed inside capsules, what enhances them security, and in-second, center masses capsules turns out ahead her center pressure, what provides aerodynamic sustainability capsules in flight;
  - in every cell fits one thing seed;
  - solution flooded in shape before complete filling cells;
  - the form from seeds fits in freezer camera
complete freezing solution (for implementation technology in field conditions in quality freezer cameras can to be used container from dry ice);
by ending freezing solution carried out notch capsules of shape for subsequent aerial seeding.

3.2. How is it possible to obtain seed capsules at the lowest cost?
Analysis existing methods of seed encapsulation to increase the efficiency of aerial seeding revealed drawbacks, the main of which are: increased injury to seeds and the impossibility of subsequent directive sowing [17]; insufficient density of the capsule outer shell for aerial seeding [18] and the impossibility of implementing the method in the field [17-20]; insufficient density of capsules, allowing only surface aerosol seeding [19, 20].

To assess economic efficiency a number of common indicators have been identified aerial seeding (table 1), including and costs for encapsulation. Let's list the main ones:
- overall performance of the complex;
- survival of seedlings;
- the cost of the hardware component of the technology, including delivery systems;
- seeding cost 1 hectare.

Table 1. Values of indicators of economic efficiency aerial seeding of Scots pine seeds, depending on the cost of encapsulation.

| Index                               | Developed technology | Technology 1* | Technology 2* |
|-------------------------------------|----------------------|---------------|---------------|
| Total productivity of the complex, ha/h | 7                    | 7.5           | 7.3           |
| Survival rate**, %                  | 70-80                | 50-60         | 45-50         |
| Cost of the carrier vehicle         | 700-800/             | 700-800/      | 700-800/      |
| UAV with seeding device, thousand rubles | 150-200             | 150-200       | 150-200       |
| Sowing cost per hectare, thousand rubles | 8.0                 | 9.0           | 9.5           |

* Technologies 1 and 2 include capsule production processes corresponding to Technologies 1 and 2 discussed in the introduction

The comparison of the developed technology with some of the technologies discussed in the article showed that the savings when using the developed method as part of the entire aerial seeding process is on average 1-2 thousand rubles per hectare.

To improve the technological process of encapsulation and its integration into the aerial seeding process in the future, it is necessary to conduct studies that study the influence and interaction of the chemical composition of the solution for freezing, the introduction of fillers and their proportions on the design of the seeding apparatus and the technological modes of the aerial seeding process. Moreover, it is necessary to check the influence of the temperature conditions of aerial seeding on the seeding efficiency of frozen capsules.

Conclusions
The study analyzed various existing methods of high-precision aerial seeding of conditioned seeds, revealed their main advantages and disadvantages. At the same time, the emphasis was placed on technological similar approaches and the most commonly used types of unmanned aerial vehicles. It was concluded that none of them guarantees truly accurate seeding, while having a rather high cost of the hardware and laboriousness of encapsulating seeds.

As a result, we have proposed our own unique method that ensures the accuracy of seeding by freezing the seed capsules. This approach has a low cost of the encapsulation process in the field, and the aerodynamic stability of the capsule in flight is achieved by changing the physical and mechanical characteristics of the capsule and the location of its center of mass in front of the center of pressure.

In this regard, we can conclude that in the course of the research the tasks set in the introduction were solved.
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