LABORATORY-SCALE PLANT FOR SEED GERMINATION AND PLANT DEVELOPMENT MONITORING

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Acknowledgements: The research described in this publication was made possible in part by R&D Support Program for undergraduate and graduate students of PetrSU, funded by the Government of the Republic of Karelia.

Abstract: Generally, R&D works urge researchers to create their own laboratory equipment. The paper describes an approach to creating a laboratory-scale plant which allows tests germinating ability of seeds by two methods and monitoring the plants growth progress further while modeling various ambient conditions. Based on patent information retrieval conducted, analysis of scientific and technical literature, and systemization of the selected material, the technical design assignment was worded. As a result of the comparative analysis performed using the method of function, structure, and technology analysis and synthesis of technical solutions, the laboratory-scale plant design has been developed which is up to all the set requirements. This laboratory unit design is distinguished by its versatility, low cost, simple structure, accessibility of materials employed, and it does not need any utility connections.

Keywords: training equipment, germination table, germinating ability of seeds, quality of seeds, Jacobsen method, Rodewald method.

1 Introduction

Classically, at educational institutions, laboratory works are viewed as the major tool to form practical abilities and skills in students. So, I. Yu. Ermienko and A. V. Struchkov (2018) note that when studying general engineering and special subjects, laboratory classes allow comprehending the covered theoretical material more profoundly and ingraining it more deeply, and the quality of knowledge depends on obtaining valid results of experimental studies confirming the theoretical knowledge. A. A. Isaev, I. A. Sabanaev, and A. V. Dmitriev (2013) indicate there are two approaches to providing educational institutions with specialized laboratory equipment: purchase of commercial equipment and in-house development of the laboratory setup. However, as pointed out by A. A. Shapovalov and L. E. Andreeva (2018), currently, most equipment for general laboratory works and practical classes in physics still contain classical measuring devices and do not enable students to master modern sensors of physical values, software and hardware complexes. Hence the authors conclude that to solve problems associated with repeatability of laboratory works and outdated equipment, students can be engaged into designing their experiments according to certain scenarios. O. P. Matveev (2016) notes that the most valuable equipment is one that can be used not only for completing scheduled laboratory sessions but also for students' research activities carried out within end-of-year and final qualification works. As an example, the laboratory unit developed by postgraduate student S. Yu. Lupov and master degree student E. P. Fradkina (2009) for the "Digital signal processing" training course can be cited.

Generally, the existing laboratory equipment is designed for highly specific tasks and a limited set of operations, and its price is frequently higher than that of similar industrial plants due to it being manufactured in small lots. As a result, due to their limited budget, far not every educational institution can afford equipping its laboratories with professional laboratory-scale systems. Meanwhile, the use of industrial plants at educational institutions for the purposes of training students and conducting experimental research is associated with a number of difficulties, such as complexity of connecting them to utilities of the laboratory. Alongside this, industrial equipment features considerable dimensions, and its performance and resource (water, electric power, etc.) consumption are outsized for the purposes of experiments.

Patent information retrieval conducted to find out the technical development level of seed germination methods and development trends of industrial and laboratory equipment for starting seeds and subsequently monitoring the growth progress of sprouts has shown there is considerable potential as for creation of multi-purpose laboratory equipment. Such systems must incorporate a combination of several methods for germination of seeds, as well as the option of monitoring development progress of the resulting sprouts within one piece of equipment.

Creation of in-house laboratory equipment by own resources of an educational institution solves several problems at once:

- it allows engaging students into practical work and thus consolidating their theoretical knowledge, practical skills, and abilities received during training;
- it helps setting up interdisciplinary communication of students from different focus areas of training (designers, mechanical engineers, production engineers, operations specialists, electrical engineers, and so on);
- a plant targeted at solving specific research problems can be obtained with the least possible material resources;
- it makes possible for the educational institution to equip its laboratory with a plant which can be modified for new tasks later, as the institution keeps all drawings, diagrams, microcontroller firmware source code, and any other information pertaining to creation of the plant;
- it enables the educational institution to expand its laboratory equipment stock.

All the above makes the topic of the paper relevant. It describes research conducted at Petrozavodsk State University as a result of working on creation of a new versatile design of a laboratory-scale plant. The plant allows germinating seeds by two different methods – the Rodewald and Jacobsen ones, – as well as monitoring development of seedlings with an option of modeling various ambient conditions.

2 Literature Review

Graduates will succeed in studying features of specific industrial units and mastering their use even on the job, if they have a solid knowledge of theory and practical skills. Among other things, to gain such skills in terms of evaluation of the quality of planting material, students of forestry focus areas of training need modern laboratory-scale systems enabling them to not only germinate seeds, but also monitor further development of the plants.

As noted by O. I. Gavrilova, K. V. Gostev, and M. V. Zhuravleva (2015), there are numerous seed germination methods: germination in bags, germination in a sponge, germination on paper towels in inclined containers, as well as the frequently observed methods of germination in Petri dishes, boxes, or other vessels. However, the most broadly used seed germination methods are the ones involving special devices termed germination tables. For example, this kind of equipment using the Jacobsen method is used in forestry seed stations for seed control. UN FAO guide to forest seed handling edited by R. L. Willan (1985) lists recommended equipment to test seeds for germinating ability, too, among which Jacobsen and Rodewald type apparatuses and germination chambers are mentioned.

The Jacobsen method is approved by the International Seed Testing Association (ISTA); it allows starting seeds on special circular paper filters (Jacobsen Germinators, 2022). The paper filters are placed on the germination plate (a special slotted plate) under which there is a water basin with heated water. The filters make up spirals with wicks reaching into the basin and supplying moisture to the seeds. Seeds placed on the paper filters are covered with tapered glass hoods; above the germination plate, there are lamps for lighting the seeds. Thus, when starting seeds with this method, one can control all principal conditions of germination: humidity, heat, and light (The BCC Germination Table, 2016).

The Rodewald method, which is also approved by ISTA, is another widespread industrial method for checking seeds for germinating ability. It is used successfully for forest and agricultural seeds in tasks when the probability of seed fungal infection risk needs to be lowered (Rodewald Germinators, 2022). The Rodewald method implies placing paper filters on a tub filled with silica sand. The sand tub is located above a temperature-conditioned water basin. So, seeds get wetted via the silica sand, and there is a transparent hood covering them to prevent the sand from drying. With its special design, condensate water does not drip into the sand, and the transparent hood can be opened for ventilation as required.

Body parts of industrial Jacobsen germinators are manufactured from stainless steel. The main elements of such germinators are: stand, water basin, and seed germination tubs. Inside the stand, thermal control water circulation system components are located: the heat exchanger tank with its tubular electric heater and cooling plant, circulation pump, solenoid valves, and the control unit (PLUS.271266.001RE "APS-1 Germinator. Operation manual", 2018). More advanced systems are designed with fine trunk and circulation water filters, and their control units have archive memory functions for storing temperature parameters and a PC connectivity option for information exchange. To maintain the required water level in the basin, industrial germinators are usually connected to water supply and sewer utilities systems of the building.

In the Jacobsen apparatuses, an important experiment repeatability condition is the precise maintenance of the water level in the basin, which is exactly what was demonstrated by S. K. Kamra (1968) using pine tree seeds. Industrial systems have an overflow pipe to set up the accurate water level. Current regulatory documents specify that the water level in the germinators has to be maintained 2-3 cm below the seed germination plate (GOST 13056.6-97, 1998).

In all industrial germinators, the temperature of seeds is maintained by heating the water in the basin. The accuracy of water heating is controlled by water temperature sensors. However, regulatory documents require maintaining not the water temperature but that of the plate where seeds are located at a certain level. To improve the temperature maintenance accuracy, modern devices use special side-mounted temperature sensors placed just under the paper filter (Operating and maintenance instructions for Jacobsen germination table, 2001); these allow setting up the unit more accurately. As for the control system of modern germinators, it allows creating several control profiles, specifying daily and weekly cycle of switching on heating and temperature maintenance, as well as the pattern of lamps being turned on for lighting.

Anyway, the capacities of industrial germinators designed for a large number of samples loaded simultaneously are outsized for the tasks of conducting student laboratory and scientific research works. So, industrial Jacobsen apparatuses can hold up to 120 samples and more at the same time. Meanwhile, to train students, a compact and affordable structure which can fit into a classroom is needed.

T. Sizmur, K. R. Lind, S. Benomar, and H. Vanevery (2014) note that germination tables are expensive, they provide equal conditions for all samples, which is not always good for research, and they are not suitable for studying roots even though germinated seeds are usually transplanted during studies. This is why they suggest a simple and inexpensive test unit for germinating and studying development of roots which provides controlled humidity and contact with the required nutrients for each seedling. Another inexpensive and affordable design for germinating grapes is suggested by S. Larsen and J. Bruce (2022). It is based on a commercial plastic box of around 70 liters volume, and heating is performed by a conventional incandescent bulb. There is a fan and reflector used for more uniform heating; they also protect the plastic box cover from the overheating hazard.

Sometimes, drying chambers with Petri dishes are used as seed germinators; for example, O. Gonzalez-Lopez and P. A. Casquero (2014) used the chambers to study germination of food culture seeds successfully. Scientists put forward technical solutions to improve current designs, too. So, D. M. Alm, R. A. Garves, E. W. Stoller, and L. M. Wax (1997) suggested using a special germination cabinet with 16 separate chambers containing 15 Petri dishes each. In all chambers, the temperature is measured independently, and the temperature is changed and monitored by the computer.

As Russia's forestry is oriented to the use of root-balled seedlings in forest renewal, another task for the system in question can be to study development of plants. For example, at forest nurseries, to find out the quality of seedling roots and to check the roots for defects, they use special tables for test germination of roots (PGC (PRK) table for test rooting of seedlings, 2022). However, simpler designs of equipment for studying the growth of roots are known. So, M. A. Raikes (1936) suggested a simple structure in the form of a bucket, with water filling a special ring-shaped recess along the perimeter and the wet chamber covered by a transparent lid with a pluggable opening through which water can be replenished. Seeds are placed on special filter paper strips, the top ends of which are dipped into the water-filled recess.

Simple plant growing structures are offered, too; for example, Around Home Creations LLC suggested a design for growing vegetable cultures from seeds in which lighting is provided for seeds and sprouts, and so is heating by heating mats (Build a Seed Starting Rack, 2022).

3 Research Methodological Framework

The objective of this paper consists in developing a laboratory-scale plant which allows both germinating seeds and monitoring further development of seedlings.

The following were outlined as the research tasks:

- to conduct patent information retrieval in relation to known state-of-the-art seed germination systems;
- to analyze known designs in terms of highlighting their advantages, disadvantages, and operational capacities;
- to identify requirements for the laboratory-scale unit being created;
- to suggest an original design of the laboratory-scale plant ensuring both germination of seeds and monitoring of their further progress.

When completing the set tasks and achieving the objective, the following methods were used:

- patent information retrieval and analysis of scientific and technical literature with subsequent systemization of the material collected;
- the comparison method which allowed finding out distinctive features of the designs and methods in question and revealing their advantages and disadvantages in certain operational conditions;
- the method of function, structure, and technology analysis which allowed viewing the studied equipment from various viewpoints, more specifically, in terms of their functional capacities, structure, materials used in the design, design solutions applied, and from the viewpoint of effectiveness of its use in various process chains;
- the method of synthesis of technical solutions which allowed suggesting new technical solutions concerning the structure, design, and tooling of the laboratory-scale plant being created.

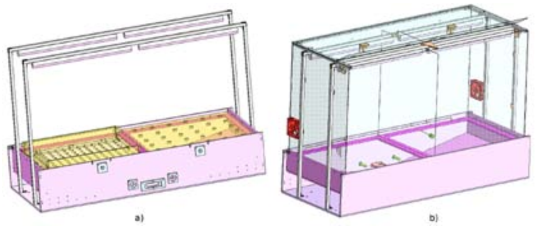
4 Results and Discussion

As a result of the patent information retrieval and analysis of scientific and technical literature conducted, the information was collected which allowed finding out the technical development level of equipment and technologies in relation to seed germination equipment and that for growing plants from sprouted seeds. Systemization of the collected information enabled the authors to word the technical assignment for developing a new design of the laboratory-scale plant with extended functional capacities, taking into account development trends of similar equipment.

Comparative analysis of known technical solutions allowed identifying distinctive features of various designs of seed germination units and the plant growth progress monitoring ones, as well as methods used in them. Their advantages and disadvantages in certain operational conditions were analyzed, too.

As a result of the work, it was decided to create an original laboratory-scale plant design which will ensure employing both Jacobsen and Rodewald methods in one unit for laboratory and student scientific research works in germinating ability of seeds. Moreover, the design in question has to feature quick transformation of the germination table into a small training greenhouse for laboratory and scientific research works in monitoring development of plants (experiments of pilot growing of timber species to identify the quality of seedling roots, etc.). On top of this, the laboratory-scale unit must feature ease of installation and need no connection to utility networks of the laboratory for operation. The resulting design is shown in Figure 1.

Figure 1 Structural elements of the laboratory-scale plant



a – when used for germination; b – when used as a greenhouse with screens

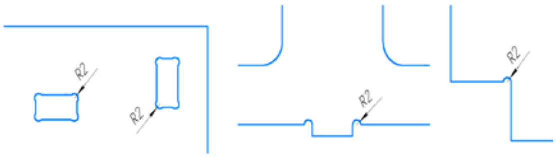
Source: compiled by the authors

The design in question belongs not to industrial setups, but to laboratory-scale training units, so some design and technological solutions have been adopted to make it simpler and cheaper. These solutions will not limit the capacities of the germination table for training and conducting student scientific research works.

So, if the number of simultaneously loaded samples is decreased up to 60 pcs for working with the table according to the Jacobsen method, it becomes possible to markedly reduce weight and size of the structure and even to install it on a standard classroom desk.

In industrial plants, stainless steel is used, but this is an expensive material which is also hard to process in conditions of university workshops: for machining it, special tools and correct machining rate selection are required. The process of welding stainless steel is markedly more difficult, as compared to the carbon steel. The use of carbon steel in design could have made the unit evidently cheaper and could have simplified its assembly; however, susceptibility to corrosion makes it unacceptable to use carbon steel for manufacturing a basin to be filled with water. So, it was decided to opt out of steel in the body structure and use sheet polypropylene as the basin body material instead. Polypropylene is a safe and easy to wash material which is not ruined by the humid environment and can survive the 40-45°C temperature required for germination. Calculations have shown that a 10 mm thick polypropylene sheet allows getting the required strength and rigidity of the unit body while keeping the structure weight acceptable. The university workshops dispose of a CNC (computer numerical control) milling machine with a large table, so the design development proceeded from the objective to fit all body parts into a 1500x3000 mm sheet. The milling machine is used for cutting parts and making blind mortises. The structure parts are assembled with the mortise and tenon method. Initially, design of the plant parts accounted for the 4 mm diameter machine cutter, so dogbone fillets were made in the inner corners of the mortises to compensate for the cutter, and the corners of corresponding parts were slightly cut up (see Figure 2).

Figure 2 Cutting plan details for assembly from sheet material



Source: compiled by the authors

For bending parts after cutting and their subsequent assembly, it was decided to use a hot air gun and a special welder for 4 mm diameter polypropylene rods. The CNC milling machine, rod welder, and laser-cutting machine are shown in Figure 3.

Figure 3 Machines for making the body and screens of the unit

Source: compiled by the authors

For the transparent screens of the plant, acrylic sheets 3 and 2 mm thick were selected as the material. Parts were cut from the sheet with the CNC laser-cutting machine. The screen elements are quick detachable, which allows converting the seed germination table into a small training greenhouse easily and monitoring the growth of plants after their germinating from seeds.

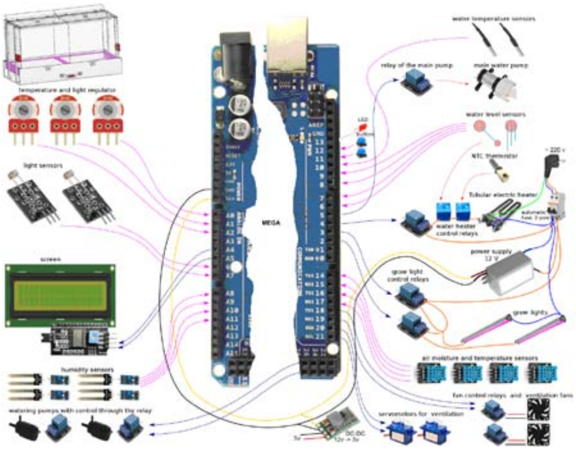
More specifically, the conversion implies mounting vertical side screens fastened by magnets on grow light posts. After that, the top screen is installed and secured on the posts with wing nuts. The top and side screens have hatches, ventilation fans, and additional sensors. The front and rear screens are hung up on the top screen profile; they can be removed in one go if plants need care. The greenhouse space can be separated with a vertical divider in the middle as required.

For automating the work of the plant and controlling the operation of sensors, it was decided to use the Arduino platform which is relatively easy to program and has a broad range of expansion boards to choose from. E. Ya. Omelchenko, V. O. Tanich, A. S. Maklakov, and E. A. Karyakina (2013) note that Arduino is perfect for designing various mechatronics systems and robots, as well as for solving more sophisticated technical automation problems. V. S. Lobodinov, S. R. Pan, I. V. Pugachev, V. N. Trofimenko, and Ya. N. Tuzko (2019) point out that accessibility and relative simplicity of launching Arduino platform-based projects allow successfully designing training plants for laboratories.

The Mega platform based on the ATmega2560 microcontroller from the Arduino family was selected for solving the automation problem for the plant being designed. The Mega platform is compatible with the most popular one, Uno, but it has a clearly larger number of digital and analog inputs/outputs, with extra memory volume at that. So, the choice of Mega results from the Uno platform lacking digital and analog inputs/outputs to connect all the required sensors and actuators of the laboratory-scale plant in question.

It was decided to use a tubular electric heater, grow lights, a water basin level pump and watering pumps, servomotors of hatches and ventilation fans as principal actuators. The plant design incorporates water and air temperature sensors, air and soil humidity sensors, illumination sensors, and water level sensors. To control the plant, buttons and variables resistors are used, and its work is monitored by readings of the screen and indicator LEDs blinking. The plant is connected to the computer through a USB port. All digital components are located in several standard IP55 class distribution boxes for electrical use. The boxes are installed in recesses of the plant body formed by the inclined basin walls. Plastic seats with holes for fasteners were designed and printed with a 3D-printer for fitting the electrical components into the distribution boxes more conveniently. The diagram of connections is given in Figure 4.

Figure 4 Circuit diagram of the multi-purpose training table



Source: compiled by the authors

Software for the platform was developed using Arduino IDE, and the utility for saving the data from the platform to the PC hard disk was developed using the Qt framework. The computer software can work both in the console mode and in the graphic user interface one. It also features the simplest WEB-server capacities, which allows viewing the information from the platform via the local area network.

5 Conclusion

As a result of the work, based on studying the technical level and development trends of methods and devices used in exploring the seed germination process and in monitoring the growth progress of sprouts, the original design of a laboratory-scale plant was suggested. Development of the laboratory-scale unit design included the entire cycle of design operations: elaboration of technical assignment, design of structural elements proceeding from the materials to be used and technical capacities of the university's industrial equipment for manufacturing them, selection of electric and digital components, development of specialized software and hardware complex for controlling operation of the plant. In relation to a number of technical solutions used in the developed design, the authors have applied to the Federal Service for Intellectual Property (Rospatent) to register industrial design rights as utility model and design patent applications. A certificate of computer software registration has been obtained, too (certificate No. RU 2022667914 dated 28/09/2022).

The developed laboratory-scale plant design features a compact size, low manufacturing cost, ease of operation, as well as versatility. The latter consists in the opportunity to germinate seeds in two methods, the Rodewald and Jacobsen ones, and monitor further development of seedlings after minor conversion.

Thus, all outlined tasks have been completed, and the set objective has been achieved in the course of the work.

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