The growing of minituber using the aerohydroponic method of potato plant cultivating

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Abstract. The article describes a new method of accelerated reproduction of the original seed material developed at the Lorch Potato Research Institute. The technological process is based on the cultivation of plants under aerohydroponic conditions using biotechnological modules - AHM (aerohydroponic module), which is based on the use of the aerohydroponic method of plant nutrition [1,2,3]. The results of testing the aerohydroponic method of growing minitubers in the spring-summer period under natural lighting conditions are presented.

1. Introduction
Nowadays, about 80% of the initial seed material of potatoes is obtained on the basis of greenhouse technologies [4,5,6], but in recent years, the interest of producers in the use of advanced technologies based on the application of hydroponic (water) and aeroponic (air) crops has significantly increased. These technologies are becoming more popular, especially for the accelerated reproduction of new and scarce varieties [4,5,6].

A technology for growing potato minicubers with a higher reproduction rate at significantly lower production costs than the traditional method of cultivation was developed at the Lorch Potato Research Institute. Cultivation of plants occurs in natural sunlight under conditions of air-water culture, which consists in growing plants without using of solid substrates in the air when treating the root space with a water-air nutrient mixture. Plant nutrition using aerohydroponic modules occurs by a combined method with active and passive feeding of the nutrient mixture to the roots of plants, carried out by volatile and non-volatile feeding circuits, functioning independently of each other. The presented technology of growing plants on AHM biotechnological modules, under natural lighting conditions, can significantly reduce production costs in relation to inventory costs, pesticides, fertilizers, water, labor and financial resources, electricity, giving low cost and very high competitiveness to the agricultural products [7,8,9,10,11].
2. **Research Objectives**
- To study the effectiveness of growing minitubers of new and promising varieties and hybrids of potatoes using the aerohydroponic method.
- To determine the quantitative and qualitative characteristics of the grown material under conditions of aerohydroponics varieties with different ripeness groups;
- Assess the productivity of aerohydroponic minitubers when grown under natural lighting conditions;
- Conduct a production audit and justify the economic efficiency of the aerohydroponic method use of growing minicubers in the process of original seed production of potatoes.

3. **Materials and methods**
Minitubers were grown using a prototype of a biotechnological module, AHM powered by a single pump at 0.7 MPa, 100W, 12/24V. The module is a box, inside of which an aerohydroponic and hydroponic nutrient solution supply system is mounted. The hydroponic part consists of a hydraulic reservoir (1) with a water displacement of 150 l, in which the lower part of the plant roots is wetted and at the same time serving as a reservoir for the liquid supplied through the aeroponic box system. The hydraulic reservoir is equipped with sedimentation tanks (2) with filters and taps for draining or adding water.

![Universal aerohydroponic module](image)

**Figure 1.** Universal aerohydroponic module: 1-hydraulic reservoir, 2-sedimentation tanks with filters and taps; 3-side cover; 4-front (rear) folding door; 5-tube with spray guns; 6-transplanting cover; 7-sprayers; 8-racks for mounting the plant containment system.

The active power system is driven by a 350W water pump with a voltage of 220V. The passive power system is independent of power systems and operates on an ongoing basis.

The technological process of growing on an aerohydroponic installation is characterized by the following technical and biological features.
- The installation is an autonomous system for growing plants, with the possibility of operation in natural or artificial environmental conditions.
- The design is mobile and made in a modular design, which, if it is necessary to grow a large number of one varietal accessory seeds, makes it possible to complete several plants into a single
integrated unit. In this case, all installations are powered by a single power supply system, operating from a single pump, which significantly relieves the power supply network and reduce production costs.

- The design is universal in purpose and can be used to grow a wide range of different crops.
- Plant vegetation occurs in a semi-automatic mode in natural or artificial environmental conditions.
- The plant nutrition is carried out on the installation in a combined active-passive mode, taking into account the requirements for nutrient elements at various stages of growth and development.
- The installation allows to increase the density of plants per unit area and significantly increase the quantitative yield of minitubers per square meter.
- The transplanting surface of the installation has a coarse perforated surface, as a result of which the planting layout is not limited to the strict placement of planting cells. This makes it possible to place plantings with any layout for any crops, starting from a layout of 25x25mm or more, depending on technological requirements. The total area occupied by the installation coincides with the area for planting and is \(1800 \times 660\) mm (1.18 sq. m).

Aerohydroponic plants in the cultivation process allow to carry out targeted measures to initiate and stimulate reproductive processes in certain phases of plant growth and development, as well as apply phased harvesting of ripening seed material with visual control of tuber development;

- Installations are equipped with plant-fixing devices to maintain them in an upright position during development;
- The design of the aerohydroponic installation provides for the fastening of light sources for implementing the method in enclosed spaces.
- A technical solution for the operation of electrical equipment provides for the equipping of an independent energy source (solar panels).

The main advantages of the module are the low-cost technological process of growing, mobility and the possibility of operation in the spring-autumn period in isolated open areas or in greenhouses, which eliminates the significant costs for the acquisition and operation of lighting sources and climatic equipment necessary for the operation of installations in enclosed spaces.

Two installations of the aerohydroponic module AHM were located at the experimental site of the Gorsky State Agrarian University. Minitubers were grown under natural lighting conditions in the spring-summer period with a differentiated nutrition scheme. A sufficiently spacious volume of the root space provided complete visual monitoring and careful handling of the roots with multiple collection of minitubers. Reliable restriction of light access to the root system avoided unwanted exposure of the roots. The experiments used varieties Impala, Udacha and promising hybrids of potato selection by Gorsky State Agrarian University. Test tube microplants, after thoroughly washing the roots from the nutrient medium, were planted immediately on the aerohydroponic module without preliminary growing.

The layout of plants on the module is 190×190 mm, the total number of seats is 48, the total area of the module for planting is 97×65 cm (0.63 m²).

The cycle of operations at the aerohydroponic installation began with the planting of test tube plants directly in the module. Before planting, the plants were carefully and thoroughly washed from the residues of the agarized medium to prevent agar-agar residues from entering the active nutrition system.

In the experiment with the aerohydroponic installation, various compositions of macro- and micro-salts were used, which, according to the results of previous studies, most fully meet the requirements of the technological process for producing minitubers. For the first phase of plant growth and development, a nutrient solution with the following content was used. For the first phase of plant growth and development, a nutrient solution was used with the following macrosalts in (mg/L): N (85), P (45), K (180), Ca (60), Mg (35), pH (5.8–6.0), EC (0.8); for the second phase: N (45), P (30), K (90), Ca (35), Mg (20), pH (5.8–6.0), EC (0.7); for the third phase: N (70), P (45), K (200), Ca (60), Mg (35), pH (5.8–6.0), EC (1.2). The content of microsalts in the solution in (mg/l) is presented in the following composition: Fe-EDTA (8), B (0.5), Mn (0.5), Zn (0.1), Cu (0.05), I (0.63), Co (0.006), Mo
(0.1). The electrical conductivity (EC) of environment varied depending on the phases and timing of the growing season; on the whole, it was maintained within 0.7–1.3. Control and adjustment of pH was carried out every 2-3 days. The solution was changed after 30 days. During operation, the volume of the nutrient solution was replenished as mineral elements were removed and transpiration losses.

The technological regime of feeding the nutrient solution in the daytime and at night during the growing season was as follows. The first mode: 60 days from 6–00 h to 22–00 h, cycle: 1 min. - work and 9 min. - break; at night from 22–00 h to 6–00 h, cycle: 1 min. - work and 29 min. - break. For 30 days, the pump runs 3360 minutes or 56 hours (56 hours × 100 watts = 5.6 kW). The second mode: 30 days from 6–00 h to 22–00 h, cycle: 1 min. - work and 19 min. - break; at night from 22–00 h to 6–00 h, cycle: 1 min. - work and 29 min. - break. For 30 days, the pump runs 1980 minutes or 33 hours (33 hours × 100 kW = 3.3 kW). The third mode: 30 days and until the end of the growing season from 6–00 h to 22–00 h, cycle: 1 min. - work and 29 min. - break; at night from 22–00 h to 6–00 h, cycle: 1 min. - work and 59 min. - break. For 30 days, the pump runs for 1080 minutes or 18 hours (18 h × 100 kW = 1.8 kW).

The first 56 days used the first solution. After this the solution was changed to a second, stimulating, and kept for 14 days. After this, the plants were transferred to a third solution until the end of the growing season. The concentration of macro-, meso- and micronutrients was adjusted weekly. During the growing season, laboratory testing of leaf samples of plants for viral infection by enzyme-linked immunosorbent assay (ELISA) was performed.

Tubers were removed after they reached 20–30 mm in diameter every 7 days. After harvesting, the tubers were treated with a 0.1% sodium hypochlorite solution, followed by rinsing in water as a preventive measure to avoid bacterial contamination. The collected minitubers were dried at high relative humidity for a week, after which they were kept at temperature of 20–25 °C for 3-5 days. Then the minitubers were stored according to traditional technology at a temperature of 3-4 °C.

Table 1. Quantitative yield of different size fractions of minitubers of various potato varieties in an aerohydroponic installation.

| Varieties     | Fraction, mm | Average weight of the 1 tuber, g | Number of tubers by fractions, pcs/% | Number of tubers on average per 1 plant, pcs |
|---------------|--------------|-----------------------------------|--------------------------------------|-----------------------------------------------|
| Hybrid 10.3/288 |              |                                   |                                      |                                               |
| 10-15         | 1-3          | 446/13.1                           | 9.3                                  |                                               |
| 15-20         | 3-10         | 293/8.6                            | 6.1                                  |                                               |
| 20-25         | 10-15        | 1598/47.1                          | 33.3                                 |                                               |
| 25-30         | 15-25        | 845/24.9                           | 17.6                                 |                                               |
| 30-35         | 25-30        | 149/4.4                            | 3.1                                  |                                               |
| ≥ 35          | Over 30      | 63/1.9                             | 1.3                                  |                                               |
| Total tubers |              | 3393/100                           | 70.7                                 |                                               |
| Hybrid 10.11/765 |            |                                   |                                      |                                               |
| 10-15         | 1-3          | 288/8.6                            | 6.0                                  |                                               |
| 15-20         | 3-10         | 368/11.0                           | 7.7                                  |                                               |
| 20-25         | 10-15        | 1632/48.7                          | 34.0                                 |                                               |
| 25-30         | 15-25        | 799/23.8                           | 16.6                                 |                                               |
| 30-35         | 25-30        | 167/5.0                            | 3.5                                  |                                               |
| ≥ 35          | Over 30      | 99/2.9                             | 2.1                                  |                                               |
| Total tubers |              | 3353/100                           | 69.9                                 |                                               |

According to the results of the studies, at the aerohydroponic plant from 48 plants of the hybrid 10.3/288 planted in 2017, 3393 tubers of various fractions were obtained. The maximum number of tubers is 1598 pcs i.e. 33.3 pcs/plant - corresponded to a fraction of 20-25 mm in size (i.e., a standard fraction) and a weight of 10-15 g, which amounted to the maximum percentage (47.1%) of the total number of tubers per installation. For the remaining fractions, much less tubers were obtained: 845 tubers, or 17.6 pcs/plant of fraction of 25-30 mm; 149 tubers, 3.1 pcs/plant of fraction of 25-30 g; 63 tubers, or 1.3 pcs/plant of fraction over 30 g.
According to the results of research, on average over the year of research was formed 70.7 pcs/plant by hybrid 10.3/288, 69.9 pcs/plant by hybrid 10.11/765.

In 2018, at the aerohydroponic installation, standard tubers for a hybrid 10.3/288 – 2655 pcs and a hybrid 10.11/765 - 2697 pcs were obtained, in total, two hybrids in special plants produced 5352 pieces of standard tubers.

Research 2016-2018 with the minituber creation of hybrids 10.3/288 and 10.11/765 on an aerohydroponic installation, were shown the formation of higher plants with a larger leaf surface area in comparison with greenhouse specimens. A positive correlation of characters was at hybrid 10.3/288 - 96.0 cm and 0.68 cm². Tuberization of hybrids 10.3/288 and 10.11/765 began on average on the 23rd and 21st days, respectively, after the planting of meristemic plants.

**Table 2.** Indicators of the assimilation surface and the beginning of tuberization in an aerohydroponic installation.

| Varieties    | Year of study | Plant height, cm | Leaf surface area, cm² | Start of tuberization, days |
|--------------|---------------|-------------------|------------------------|-----------------------------|
| 10.3/288     | 2016-2018     | 96                | 0.68                   | 23                          |
| 10.11/765    | 2016-2018     | 86                | 0.63                   | 21                          |
| Average      |               | 91                | 0.66                   | 22                          |

Under greenhouse conditions in the soil substrate, tuberization of these hybrids occurred on the 29th and 25th days, respectively, which significantly increases the vegetation period of the plant.

The variety Udacha planted in the installation for the budding phase formed 81 cm in 2016 and 91 cm in 2017. Plant growth and leaf surface area had a direct relationship. For one plant, it was formed 0.55 cm²/plant in 2016, and in 2017 this figure was 0.68 cm²/plant. The beginning of the formation of tubers was recorded on the 25th and 23rd day after the planting of meristemic plants in the variety Udacha. The indicators of the variety Impala were inferior to the variety Udacha, only the beginning of tuber formation for this variety was recorded 1-2 days earlier, which is not considered a significant change in the context of varieties of one ripeness group.

The authors of the AHM installation indicate that more than 1500 minitubers can be obtained from one square meter of usable area in natural light to variety Udacha. In our experience, from 60 plants planted on an area of 2.28 m², 3467 minitubers were obtained.

The quantitative yield of minitubers per plant averaged 57 pcs. Tubers from 10 mm and above were taken into account. The output of the minitubers of optimal size from 20 to 30 mm in diameter was 75%. The number of tubers of a larger fraction (> 30 mm) is about 7%.

**Table 3.** Quantitative yield of different size fractions of minitubers of various potato varieties in an aerohydroponic installation.

| Varieties | Fraction, mm | Average weight of the 1 tuber, g | Number of tubers by fractions, pcs/% | Number of tubers on average per 1 plant, pcs |
|-----------|--------------|---------------------------------|-------------------------------------|---------------------------------------------|
| Udacha    | 15-20        | 3-10                            | 339                                 | 7.1                                         |
|           | 20-25        | 10-15                           | 1739                                | 36.2                                        |
|           | 25-30        | 15-25                           | 700                                 | 14.6                                        |
|           | 30-35        | 25-30                           | 103                                 | 2.1                                         |
|           | ≥ 35         | Over 30                         | 49                                  | 1.0                                         |
| Total tubers of variety Udacha | Over 30 | 3136/83% | 65.3 |
| Impala    | 10-15        | 1-3                             | 198                                 | 4.1                                         |
|           | 15-20        | 3-10                            | 306                                 | 6.4                                         |
|           | 20-25        | 10-15                           | 1612                                | 33.6                                        |
|           | 25-30        | 15-25                           | 672                                 | 14.0                                        |
|           | 30-35        | 25-30                           | 109                                 | 2.3                                         |
|           | ≥ 35         | Over 30                         | 48                                  | 1.0                                         |
Total tubers of variety | 2017 year of research | 61.4 |
---|---|---|
Udacha | 10-15 | 2945/83% | 61.4 |
| 20-25 | 4.3 |
| 25-30 | 3.2 |
| ≥ 35 | Over 30 | 1.9 |
Impala | 10-15 | 3217/85% | 67.0 |
| 20-25 | 34.4 |
| 25-30 | 14.8 |
| ≥ 35 | Over 30 | 1.9 |

According to the results of studies, it can be noted that one plant of variety Udacha formed in 2016 65.3 pcs/plant, in 2017 - 71.4 pcs/plant and of variety Impala - 61.4; -67.0 pcs/plant, respectively, by year of study.

The results of the studies showed that on the aerohydroponic installation from planted 48 plants, 3136 tubers with a different fraction of the variety Udacha were obtained in 2016. The maximum number of tubers (1739 pcs) was formed by plants with a fraction of 20-25 mm and a weight of 10-15 g.

For 90 days of the installation operation, for the production of 3467 pcs minitubes, electricity consumption amounted to 10.7 kW, water consumption of 2600 liters. The average number of minitubers received per plant was 57 pieces, of which more than 82% are tubers of the optimal fraction, ready for planting in open ground and 18% are tubers of a smaller fraction that can be planted in protected ground.

In monetary terms, the cost of raw materials for the production of 3467 pcs minitubers amounted to a little less than 200 rubles, of which about 56 rubles for electricity, 73 rubles for water and about 1.28 kg of micro and macro salts of salts for 71 rubles for nutrition.

Table 4. Efficiency of using the aerohydroponic method under natural lighting conditions, variety Udacha.

| Source data | Costs | Tuber were grown | Actual costs in rubles |
|---|---|---|---|
| total plants | vegetation | electric power | Water | Nutrition | Total per 1 plant | for all material | per 1 minitube |
| 60pcs | 90 days | 10.7 kW | 2600l | 1.28 kg | 3467 pcs | 57pcs | 200 rub. | 3.08 W |

The energy consumption for obtaining 1 minicub was 3.08 W compared with the fact that under artificial conditions using sodium lamps DNAT-400 and LED lamps, lighting costs ranged from 1120 to 1680 W per 1 minicub [2]. That is, if the cost of 1 minituber under artificial lighting, the cost of electricity ranged from 6 to 9 rubles, then under natural lighting conditions, they amounted to less than one ruble. The results were compared with options for a commensurate area with the same number of plants planted, in different lighting conditions and for different methods of cultivation.

4. Conclusions

On the basis of the obtained experimental data, the features of plant growth and development, and tuberization were identified. The quantitative and structural analysis of the minituber crop in aerohydroponic culture under natural light conditions was carried out. It was revealed that on average...
one plant can get more than 20 pieces of minicubers with a quality not inferior to minicubers obtained by traditional methods in greenhouse culture.

The use of natural lighting from spring to early autumn avoids high energy costs, compared with artificial lighting, which is necessary indoors or during autumn-winter circulation in greenhouses.

The method of root nutrition by aerosolization of the root space with a water-air nutrient mixture is fundamentally different from the existing one in current aeroponic systems. Aerosolization occurs in a non-contact air-shock way due to the dispersion of the nutrient fluid with compressed air. The nutrient liquid crushed by the air flow forms a high-quality aerated water-air suspension mixed with nutrients, water and oxygen, and increases the efficiency of nutrient absorption by the root system.

The aerosol method of preparing a nutrient mixture with further supply to plants is characterized by the durability and reliability of the equipment involved due to the fact that the working bodies of electrical equipment, unlike hydraulic systems, do not come in contact with an aggressive nutrient medium.

Minimizing the use of chemicals and mineral fertilizers very seriously increases the environmental friendliness of production and helps reduce the harmful effects of chemical emissions on the entire ecosystem.

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