Innovative technology for growing potato minitubers on aerohydroponic devices

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Abstract. Technologies for the production of minitubers use the controllable conditions of the created aerohydroponic device to automate the process at the stages of plant development. The developed new device maximizes the use of the area within 1 m2 and holds 60 pcs of potato plants. The device is a aerohydroponic module (AHM) designed specifically for growing minitubers in closed spaces. Such conditions make it possible to nourish plants and control each selected genotype during the growing season. The controlled device regulates the development processes of meristemic potato sprouts, conducts phenotypic observations in the winter and selects the best genotypes. The created device offers an opportunity to conduct observations in any terrain.

1. Introduction

To date, the traditional method of growing of pot culture in winter greenhouses is still the main way to obtain the original seed material of potatoes in the form of minitubers and involves very high costs and a fairly low reproduction rate [1, 2].

Significant investments, modest yield indicators and greatly increase of the minitubers cost make them uncompetitive and its production unprofitable. Since the original seeds are highly demanded in seed production, and its production is unprofitable, the state allocates special subsidies to seed-growing farms to provide them with original seeds [3–5].

In modern production, new technologies and methods of cultivation replace traditional schemes and are capable to significantly increase production efficiency and the final cost of production [6, 7]. These technologies can fundamentally change the very principle of obtaining seed material, will significantly reduce all costs incurred in material and financial terms. Today the most effective methods for producing minitubers are technologies for growing in a water-air nutrient medium using special aeroponic or hydroponic devices. Moreover, such devices are used not only in naturally lighting vegetation constructions but also in completely enclosed spaces with an artificially created climate and lighting [8, 9]. Methods for producing minitubers based on the use of air-water technologies in aeroponic and hydroponic devices significantly increase the efficiency of cultivation and significantly reduce production costs. Compared with the traditional technology for producing minitubers in pot culture where one plant gives an average of 8-10 minitubers, use of water-air
technologies, according to different authors, increase the reproduction rate by 2.3 or more times [10–12]. Besides, these technologies do not require laborious work with soil and various equipment inherent in the traditional technology. There is no need for many manual works required during manipulations with pots, soil and its processing.

New technologies for cultivating crops in the air-water medium systematically, confidently and increasingly conquer spaces and areas of agricultural production. Today they have reached enormous proportions in the production of such important industrial crops as the cultivation of tomatoes, cucumbers, strawberries, etc. So in the production of minitubers, hydroponics showed significantly higher rates when growing potato seed material and took its place [3, 4].

However, despite the significant costs of material and especially labour resources leading to a very high cost of production with the traditional method of cultivation, manufacturers are not willing to switch to modern technologies that significantly increase production efficiency, eliminate all heavy physical work and also significantly reduce the harmful effects on the environment due to the significant conservation of water resources and the maximum reduction in pesticidal load in the cultivation of seed potatoes.

As a rule, new technologies mainly use various methods for producing minitubers under growing conditions in a water-air culture on various aeroponic or hydroponic devices [5]. All these devices are inextricably linked with volatile power systems and are directly dependent on the available electricity and electrical equipment. This circumstance is the main reasons for the fear of manufacturers switching to new technologies and lies in insufficient trust in technological equipment completely dependent on sources of power supply because unforeseen cases of failure of electrical equipment can lead to the saddest consequences.

However, more progressive manufacturers thanks to the point-based implementation of such systems in practice, and the experience of their farther use identified and studied all the disadvantages and advantages, significantly modify the systems and make the power supply partially dependent on electricity for the safe growing process [7, 8]. The easy and skilful development of new cultivation methods has opened up a huge prospect in introducing new ideas and opportunities for improving production. As soon as manufacturers faced unforeseen phenomena in terms of power supply problems, sudden accidents and a host of other adverse situations associated with changing environmental conditions, engineers immediately began to introduce automation tools into production, and the most successful solution was the introduction of intelligent control systems. It was impossible to use such improvements in old traditional technologies, less because of too high costs but the complexity of the algorithms associated with the activities inherent in working with pottery. Such work cannot be implemented on digital technology to provide a stable management system.

And for new technologies, it turned out that their close connection with electrical equipment turned this disadvantage into an advantage, and small investments made it possible to fully automate the growing process at individual stages of plant development. The introduction of automatic means of intellectual control and management into the technological process makes it possible to fully control and manage production with minimal human involvement, to ensure reliable safety in case of unforeseen incidents with power outages, excessive temperature rise, lack of lighting, etc. Automatically adjusting the initial microclimate parameters that change during the process and the specified power and lighting modes, the control maintains the operability of the control mechanisms involved in the onset of adverse conditions and unforeseen situations, and the new system predicts the possible development of subsequent events based on an analytical summary of constantly received data. All this, ultimately, leads to a significant reduction in the cost of the technological process of growing minitubers and a significant increase in production efficiency.

All over the world, the development of new technologies with intelligent control systems is receiving a lot of attention [11]. In Russia and abroad, there are many scientific works and publications on the introduction and use of various types of hydroponic systems in the production of various crops [7, 8].
Various research institutions pay great attention to improving new technologies and creating new technological devices for growing potato minitubers to increase the efficiency and quality of the resulting seed material. Various foreign and domestic research laboratories have created new productional lines based on the principles of cultivation in aeroponics and hydroponics [12].

To reduce the extreme dependence on electricity, they began to pay great attention to such technological lines and devices that would only be partially dependent on electrical life support systems and could carry out the process of feeding the plants for a rather long time in case of an accident and loss of electricity. Such technological devices make it possible to conduct production in any terrain conditions in enclosed spaces and in light vegetation constructions as well as far from electric networks under the condition of partially or periodically renewable energy reserves (solar panels, wind generators, diesel power plants, etc.) for the necessary inclusion electrical equipment at regular intervals.

2. Methods and materials

To install such systems, it is possible to distinguish a technological device for growing potato minitubers developed at the All-Russian Scientific Research Institute of Agricultural Sciences. A.G. Lorch, patent No. 2693721. Aero-hydroponic installation for growing plants works as follows.

Before starting work, the nutrient solution fills the hydraulic reservoir in the required volume. Microplants are planted on a transplanter panel. The main aerosol nutrition of plant roots is as follows. Compressed air is supplied to the air tubes through an air hose. The airflow passes under pressure through the air nozzle of the air tube, leaves it at high speed creating a vacuum above the water tube, thereby the liquid rises through the water tubes and mixes with the air entering at high speed into small droplets. Further, the liquid in a finely dispersed state is carried away by the air stream and hitting the separator breaks up into even smaller parts turning into an aerosol suspension saturated with nutrients and oxygen. Suspension in this physical state becomes optimally available for nutrition with unique quality characteristics. A timer controls how the system turns on and off.

The aeroponic power system is switched on at longer intervals and also serves to spray the roots and to fill the cells with the elevator platform with nutrient fluid. After turning on the water pump, the liquid passes through the filtration and UV-cleaning system, is fed into the pipes of the aeroponic system and is sprayed onto the roots of the plant through sprayers. For processing the leaf surface, the dispensing valve opens and the nutrient solution is sprayed onto the sheet surface through sprayers. The reservoir is a component of passive nutrition and provides constant contact of the lower part of the roots of plants with periodically recycled nutrient solution.

3. Results

The device maximally uses the occupied space, places 60 PCs of potato plants on 1.1 m² and give 25–60 PCs and more minitubers of the standard fraction from 20 to 28 mm from one plant depending on the characteristics of the cultivated varieties.

The device is an aerohydroponic module (AHM) designed specifically for growing potato minitubers and other tuberous crops in closed spaces with an artificial climate or under natural light conditions in vegetation constructions. AHM modules allow to safely grow plants without fear of sudden loss of electricity or damage to electrical equipment. Nutrition in the module uses a combined active-passive method of feeding plants by combining the supply circuits of the aeroponic and hydroponic systems. In these systems, an energy-dependent aeroponic system actively feeds plants, while an energy-independent hydroponic system produces constant passive feeding of plants throughout the growing season. Even with a sudden loss of electricity or a breakdown of the nutrient solution pump, such separate nutrition still protects the plants from drying out the roots, and passive nutrition can fully nourish the plants until the elimination of the accident and restore the operating mode.

The table below shows the results of production tests carried out at the trial site of All-Russian Research Institute of Potato for Zhukovsky early variety excluding operator labour costs. Cultivation
took place under natural sunlight in a greenhouse, with the fulfilment of sanitary safety requirements for the conditions of the original seed production (Table 1).

**Table 1.** Growing potato minitubers in AHM of All-Russian Research Institute of Potato in natural light conditions. Variety Zhukovsky early

| planted plants. | Expenses | Minitubers grown |
|-----------------|----------|------------------|
| 60 PCs          | Term of vegetation | el. energy | water | min fertilizer | total | on 1 bush |
| 90 days         | 10.7 KW | 2600 l | 1.28 kg | 3467 PCs | 57 PCs |

As noted earlier, these modules work both indoors and in light greenhouses with a film coating in sunlight.

This method of growing in natural light in closed greenhouses with a controlled climate is very effective compared to growing in closed spaces with an artificial climate.

The advantage of this option is the lack of the need for lighting plants from artificial light sources which can significantly increase the cost of production. Such greenhouses make it possible to carry out two growing periods, even in the conditions of Central Russia, if cultivated from April to July and from August to November when there is no frost. With the lighting conditions, there is also no shortage of light both in the April month and in August, and by the end of the growing season by November, the presence of a large amount of light for plants is no longer so important.

Such greenhouses can easily turn into mini-complexes covering an area of only 35 x 35 m and produce potato minitubers on an industrial scale for five varieties immediately receiving up to 50 thousand minitubers in just one growing season.

Monitoring of modern innovative Russian agricultural production shows the high dynamism of the scientific search for adaptive low-cost, energy-saving, environmentally friendly agricultural practices that ensure the transformation of all production processes considering market needs (Table 2).

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

| Variety | Year of study | Plant height, cm | Leaf surface area, cm² | The beginning of tuberization, days |
|---------|---------------|------------------|------------------------|-----------------------------------|
| Udacha  | 2016          | 81               | 0.55                   | 25                                |
|         | 2017          | 96               | 0.68                   | 23                                |
|         | 2018          | 95               | 0.62                   | 24                                |
| Average |               | 90.7              | 0.62                   | 24                                |
| Impala  | 2016          | 71               | 0.51                   | 24                                |
|         | 2017          | 86               | 0.63                   | 22                                |
|         | 2018          | 90               | 0.65                   | 23                                |
| Average |               | 82.3              | 0.60                   | 23                                |

Our study focuses on the patterns of development of potato seed production with the rational use of methods for producing minitubers in the conditions of North Ossetia-Alania. Obtaining high-quality planting material of potato varieties of domestic and foreign selection the most biologically adapted to specific environmental dispositions is an urgent task. The performed layer of scientific work allowed us to provide favourable conditions for biochemical and physiological processes in the living cells of the culture with strict control of plant growth, physicochemical parameters of tubers and to give a comparative agroecological assessment of the potato varieties used.

We planted 48 plants in each specially equipped aerohydroponic installation and carried out various counts and observations during the growth and development of plants. Table 3 presents the results.

Plants of the Udacha variety grew faster than Impala and by the budding phase formed 81 cm in 2016, and by 15 cm more in 2017. Plant growth and leaf surface area were directly dependent, and in 2016 one plant occupied 0.55 cm², and in 2017 this indicator was 0.68 cm² per plant, the indicators for 2018 occupied an intermediate position. After the planting of meristemic plants of the Udacha
variety, tubers started to form on days 25 and 23. The indicators of the Impala variety were inferior to the Luck variety, only the beginning of the formation of tubers for this variety was recorded 1–2 days earlier which we do not consider as a significant change in the context of varieties of one ripeness group.

The quantitative yield of mini-tubers per plant averaged 57 PCs. We considered tubers with a size of 10 mm and above. Due to the forced cessation of plant vegetation, we did not collect or consider small tubers less than 10 mm in size, although, they could give a significant increase in the number of full-fledged mini-tubers. We found that the quantitative yield of the optimal minitubers from 20 to 30 mm in diameter was more than 75 %. The number of tubers of a larger fraction (> 30 mm) was about 7 %. The fraction of tubers from 15 to 20 mm was about 9 %. The fraction of small tubers from 10 to 15 mm did not exceed 7 %.

Table 3. The quantitative yield of different size fractions of minitubers of potato's varieties in an aerohydroponic module

| Variety  | Fraction, mm | Average mass of the 1st tuber, g | Number of tubers by fraction, pcs. | Number of tubers on average per 1 plant, pcs. |
|----------|--------------|---------------------------------|-----------------------------------|--------------------------------------------|
|          |              | The 2016–2018 year of research   |                                   |                                            |
| Udacha   | 10–15        | 1–3                             | 256                               | 5.3                                        |
|          | 15–20        | 3–10                            | 389                               | 8.1                                        |
|          | 20–25        | 10–15                           | 1789                              | 37.3                                       |
|          | 25–30        | 15–25                           | 750                               | 15.6                                       |
|          | 30–35        | 25–30                           | 153                               | 3.2                                        |
|          | ≥ 35         | More than 30                    | 89                                | 1.9                                        |
|          |              | Average for 3 years, Udacha variety | 3426/85 %                     | 71.4                                       |
|          | 10–15        | 1–3                             | 248                               | 5.2                                        |
|          | 15–20        | 3–10                            | 356                               | 7.4                                        |
|          | 20–25        | 10–15                           | 1652                              | 34.4                                       |
|          | 25–30        | 15–25                           | 712                               | 14.8                                       |
|          | 30–35        | 25–30                           | 159                               | 3.3                                        |
|          | ≥ 35         | More than 30                    | 90                                | 1.9                                        |
|          |              | Average for 3 years, Impala variety | 3217/85 %                     | 67.0                                       |

The results of our studies showed that for three years of research on an aerohydroponic plant, 48 planted plants yielded an average of 3426 tubers, and in a more favourable 2017 research, Udacha variety with different fractions brought 3862 tubers. Plants with a fraction of 20–25 mm and a weight of 10–15 g formed the maximum number of tubers, 1856 and 1736 PCs respectively for to the varieties Udacha and Impala.

Per one plant of this fraction, the Udacha variety provided 36.2 PCs/plant, the tubers of the other fractions were much smaller, for example, the most popular fraction of 25–30 mm counted 700 PCs in this variety, and per one plant it turned out 14.6 PCs., 25–30 gram tubers formed 103 PCs in total for installation and 2.1 PCs/plant, tubers above 30 grams formed in total 49 PCs that is one tuber per plant.

The indicators of 2017 were higher than the data of 2016, the data of 2018 occupied an intermediate position, and tubers of larger fractions of 30–35 mm and higher were formed by 48.5 % and 81.6 % of the total for the installation.

The indicators of the Impala variety were inferior to the Udacha variety for all years of research. Considering the data in the context of one variety by year of study, we noted that in 2017 the Impala variety provided 9.2 % more tubers per plant but was inferior to the Udacha variety by average indicators during the study years.

For 90 days of operation of the module, the energy consumption for the production of 3467 mini-tubers amounted to 10.7 kW, water consumption was of 2600 litres. With an average number of minitubers obtained, calculated at 57 pieces per plant, more than 82 % were tubers of the optimal fraction.
for planting in open ground and 18% were tubers of a smaller fraction for planting in the protected ground.

According to the results of our research, we note that one plant of Udacha variety formed 71.4 units/plant and Impala formed 67.0 units/plant on average over three years.

4. Conclusion

Based on the numerous research data in the field of growing potato minitubers, we can safely declare the significant superiority of aerohydroponic technologies over the traditional method of growing in pot culture and, not only in terms of competitiveness, but also in terms of the safety of maintaining and obtaining a healthy high-quality original seed material of potatoes.

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