Development and research of the effectiveness of using an automated aquaponic system for home cultivation of microgreens

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Abstract. In this study, an automated system was developed for the home cultivation of microgreens using aquaponics technology using modern technologies and a review of literary sources. The researcher was convinced that the automation system of the aquafarm is able to significantly simplify human care of the aquarium. Experimentally, the advantage of using this system over the "classic" method of growing microgreens, in terms of the rate of ascent of the stems, was tested. It was also verified that the developed automated system for a home aquapon installation has a positive effect on the biological ecosystem. Monitoring of the main indicators of water quality has shown sufficient effectiveness of this method to neutralize indicators such as nitrates. In the future, this work can become the basis for conducting a large number of experiments for longer periods and monitoring a wide range of water quality indicators and growing large types of seeds.

1 Introduction

Microgreens is a promising branch of the agro-industry for industrial and home cultivation of healthy and tasty greens. The relevance of growing microgreens lies in the fact that they are a valuable source of nutrients such as vitamins, minerals and antioxidants. Growing microgreens at home or on an industrial scale has many advantages. Firstly, this is a very simple process that does not require a lot of time and money. Secondly, it allows you to get fresh and healthy products all year round, even in conditions of limited space. Thirdly, microgreens can be used in cooking to decorate dishes and give them a brighter taste and aroma. Also, the cultivation of microgreens can become a profitable business. When growing microgreens, there is a need to solve several problems affecting plant growth: lighting and watering. Plants need bright light for photosynthesis and growth, so it is necessary to provide them with sufficient light, especially if growing takes place indoors. Another problem may be drying out or waterlogging of the soil. Micro-greenery requires regular watering, but it is necessary to ensure that the soil is not too dry or wet. At the same time, there are no ready-made automated plants for growing microgreens on the market.

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2 Relevance

Aquaponics is a part of industrial agricultural production and represents a simulation combined ecosystem of automatic and semi-automatic control of the state of the aquatic environment, temperature and lighting, with an automechanical hydroponic method of growing plants [1]. Aquaponics is a symbiosis of the existence of artificially bred freshwater animals, hydroponic crops of agricultural plants and colonies that process organic bacterial residues [2]. Vegetables and herbs are grown in containers that do not contain soil, and plants receive their nutrition from wastewater discharged from ponds. Plants feed on bacteria from fish waste products, and then this water is returned back to the pond in a purified form. These systems can be both large and small, depending on the desire and capabilities, and are potentially capable of producing fish and vegetables in large quantities.

As the researcher notes, to launch an aquapon installation, it is important to choose the right number of aquarium inhabitants in the right amount, and to maintain the well-being of the environment, it is necessary to maintain water quality, volume and quality of nutrition, and habitat design [3]. Many researchers are also confident that the profitability of aquaculture is influenced by various water parameters such as: PH, temperature, dissolved oxygen, carbonates, nitrates, ammonia, etc. [4] [5] [6]. Also, during the process, plants consume the necessary products of secretions of living organisms — chemicals (nitrogenous, potassium, phosphoric compounds, carbon dioxide, etc.) dissolved in water, and — at the same time, naturally purify and enrich it with oxygen. In this process, the need for the use of various chemical fertilizers, with a complex system of their dosing and storage, is eliminated. It is also worth noting that many researchers and developers are working on creating universal solutions for automating aquapon installations, monitoring water parameters using IoT technology [7] [8], as well as creating chatbots that have shown themselves positively for use in aquaculture [9]. Replacing water in an aquarium is one of the main maintenance activities and should be performed regularly, which leads to an improvement in a number of water indicators, so it makes sense to use an automatic water exchange system (AWES) to improve the work of an aquarist [10].

Therefore, small artificial aquatic farms can be an excellent solution for growing microgreens at home, small and restaurant businesses. Automation of this biological system using IoT technologies will simplify the process of caring for an aquafarm at home and achieve maximum aesthetics of the object for any home or work interior. And modern technologies of technical vision and neural networks can allow the user to automatically receive notifications about every parameter of ecosystem change, plant growth rate, as well as about the behavior and condition of fish.

3 Setting the task

Research objectives:
- To develop an automated system for home cultivation of microgreens using aquaponics technology using modern technologies and a review of literary sources to form technical requirements for the installation.
- Experimentally verify the advantage of using this system over the "classic" method of growing microgreens, in terms of the rate of ascent of the stems.
- To confirm the positive impact of the implementation of the developed automated system for a home aquapon installation by monitoring the main indicators of water quality.

Hypotheses:
- In an automated aquafarm, microgrowth grows faster than in a conventional plastic basket.
- The automation system of the aquafarm is able to significantly simplify human care of the aquarium.

- Hydroponic planting with constant soaking of micro-green seeds is more effective than hydroponic planting without constant soaking of seeds, and immersion of only the roots in water in an automated aquaponic installation.

4 The theoretical part

Microgreens are sprouts of vegetables and herbs at the initial stage of development, which have managed to release cotyledonous and the first real leaves. Micrograin is the initial stage of the development of edible plants and the first stage of growing it from seeds. In terms of composition, microgreens are about 2-3 times more nutritious than sprouted seeds, since they grow in the ground for several weeks, multiplying their value with soil energy, sunlight and abundant watering.

The benefits of micro-greenery:

- Very high content of vitamins C, A, E, K, PP, unique content of vitamin D and the entire group of vitamins B, phosphorus, potassium, magnesium, iron.
- Microgreens bring unique antioxidants and flavonoids to the diet, a whole set of useful essential oils, tannins.
- With a lower calorie content, it is easier to digest, not to mention protein and dietary fiber.

Initially, the choice of plants was small: beetroot, cabbage, basil, coriander. Now the assortment for germination includes dozens of different crops. After conducting a literary review of the conditions for growing most types of microgreens and the germination time, conclusions can be drawn:

- The germination capacity for most plant species should be 25 x 50 cm for 20-30 grams of seeds.
- It is not necessary to soak the seeds before planting
- Preferred growing medium is soil and/or hydroponics
- The growing time before harvesting is on average 1 week.

5 System development

To automate the process of growing microgreens in a home aquaponic system, a block diagram of the control unit (system) was drawn up, shown in Figure 1.

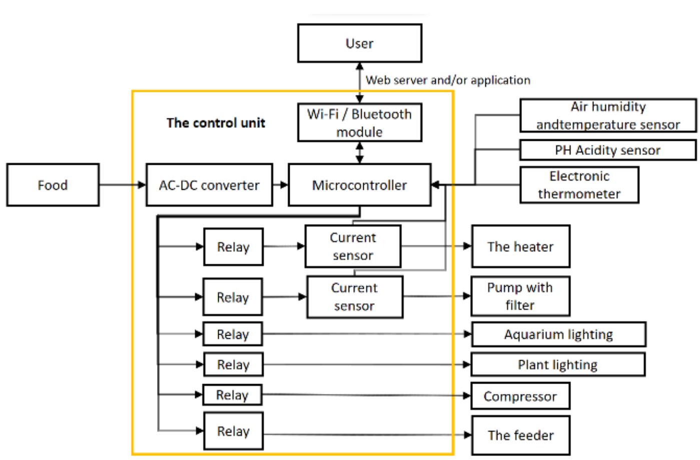

Fig. 1. Block diagram of an automated aquaponic system

An Arduino Uno/nano or ESP8266-NodeMCU can be used as a microcontroller [11] [12]. Since they are easy to use, single-board computers and Aries are too powerful for the tasks [13] [14]. Therefore, the ideal solution would be to use ESP32-WROOM-32U — these are powerful universal Wi-Fi + Bluetooth + Bluetooth LE MCU modules that can be used for a wide variety of applications, ranging from low-power sensor networks to the most complex tasks such as voice encoding and decoding and music streaming [11] [13]. There are 38 pins on board the board, which can be used for both reading/transmitting digital and analog signals, as well as the controller supports many interfaces, including high-speed SPI, Ethernet, I2S, I2C and UART.

A solid-state relay should be used to remotely control the condition of the heater, sponge filter pump, compressor, plant/aquarium lighting and feeder. In collaboration with the microcontroller, we can program and receive automatic switching on and off of the device by timer at certain time intervals, as well as implement an automatic feeder [15]. It is worth noting that it is worth using current sensors to monitor the performance of the heater and pump, since these devices are cheap for most users and fail often, this will allow you to fix the moment of failure and replace the device without harming the inhabitants of the aquarium. To measure the temperature, we will use the DS18B20 sensor, and for the upper level, the DHT22 temperature and humidity sensor, and measure the pH parameter with an acidity sensor. In the future, microcontroller modules with a camera can be installed for video monitoring of the entire installation in the absence of the owner.

Fig. 2. Explanations on the location of key elements in the design of a home aquapon installation

Fig. 3. General view of the resulting home aquapon installation

Figure 3, as a result, a compact and functional automated home aquaponic installation can be obtained from the aquaferm kit. The algorithm of the installation is shown in Figure 4, an illustration of the control and monitoring application is shown in Figure 5.

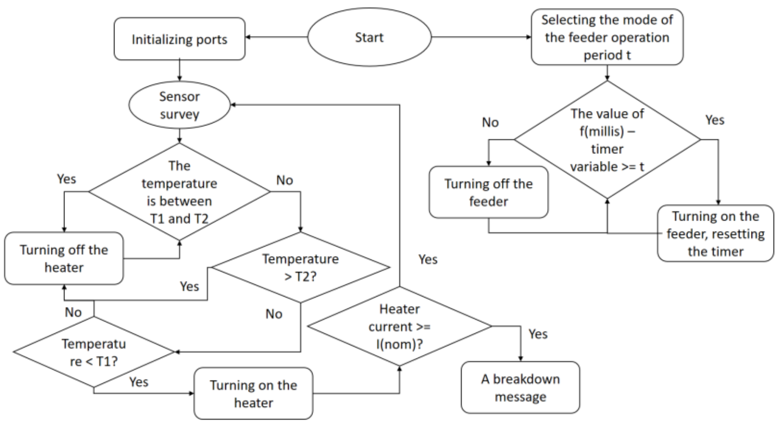

Fig. 4. The algorithm of the automation of the home aquapon installation

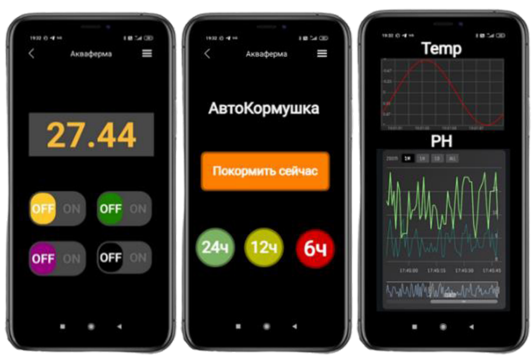

Fig. 5. General view of the application for managing and monitoring a home aquapon installation

It follows from Figure 4 that after the start of the system, the microcontroller begins to poll the sensors and waits for the selection of the feeding period of the aquarium inhabitants, hence the operating mode of the autocormer. When the time period t is selected (that is, the time interval: 24 hours, 12 hours, 6 hours), the timer starts working on millis, from the value of which the timer variable written in the unsigned long (uint32_t) type is subtracted and compared with the value of t. If the result of the distribution is greater than or equal to t, then the feeder turns on, working off the feed reset cycle, and the timer is reset to millis. Otherwise, the feeder does not work. At the same time, the actual temperature value in the aquarium is compared with the diopath stitched into the controller T1 and T2, where T1 is the minimum favorable temperature value for this type of fish, T2 is the maximum favorable temperature value for this type of fish, as well as T2 >T1. If the temperature in the aquarium is in the range between T1 and T2, not less than T1 and more than T2, then the heater is turned off. If the temperature in the aquarium is greater than T1, then the heater turns on. In this case, the heater's current consumption is compared through the current sensor with the device's nominal current consumption Inom sewn into the controller, if it is less than or not equal to Inom, then a message is sent to the user about a problem with the heater. Otherwise, the heater will continue to be turned on until it reaches the range of T1 and T2 stitched into the controller.

6 The experimental part

An experiment was conducted to test the effectiveness of the entire installation and the positive impact of the automated system on the biological ecosystem. Micro-green seeds were taken: broccoli, cauliflower and peas. The seeds were planted in an aquafarm, while cauliflower and broccoli seeds were planted in two cells. In one case, so that the water in the compartment touches (soaked) the biodegradable mat, in the other, the mat is raised slightly with decorative expanded clay, so that only the roots of plants touch the water during germination in order to avoid mold formation, as shown in Figure 6.

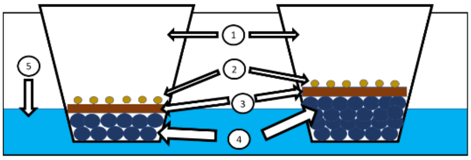

Fig. 6. Scheme of options for planting seeds in an aquafarm, where 1 – pots, 2) seeds, 3 – a biodegradable mat, 4 – decorative expanded clay, 5 – water circulating between the aquarium and the plant compartment

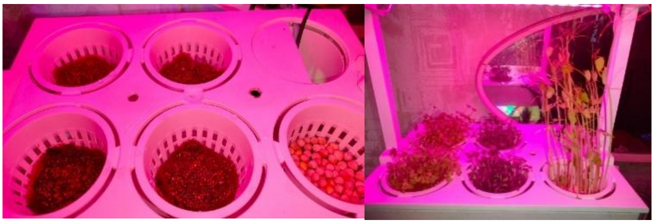

Fig. 7. Illustration "before" and "after" planting seeds in an aquafarm

Also, in parallel, the seeds are planted in the usual way in a plastic container with a wet biodegradable mat (Figure 8).

Fig. 8. Illustration "before" and "after" planting seeds in a basket

One cockerel became an inhabitant of the aquarium, in the second experiment a flock of golden barbuses and two catfish, in the third a small flock of Guppies. The obtained water quality data in the aquafarm are presented in Table 1.

Table 1. The obtained experimental data on water quality in an aquatic farm with different types of fish

	Schooling fish			Cockerel			Guppy		
Day	**NO3**	**t**	**ph**	**NO3**	**t**	**ph**	**NO3**	**t**	**ph**
1	0,2	24	5,1	0,2	26	5,8	0,4	25	6,1
2	0,4	25	6,2	0,8	27	6,1	0,8	26	6,5
3	2	27	7,1	3	26,5	7,5	4	25	6,8
4	4	27	7,6	0,8	25	6,5	2	24	7,4
5	4	25	7,8	0,8	26	7,1	1,5	25	7,6
6	4	27	8,1	0,4	27	6,8	2	26	7,7
7	4	27	7,9	0,4	29	6,5	2	25	7,5
8	3	26	8,1	0,4	28	6,8	2	24	7,6
9	2	25	8,5	0,2	26	6,9	2,5	25	7,8
10	2	27	8,7	0,2	27	7,1	2	26	7,7

The obtained characteristics of the temperature and acid background are shown in Figures 9 and 10. The adequate pH of the system is a compromise between the demands of plants and bacteria. Plants prefer a low pH value, whereas nitrifying bacteria have a pH of about 7.5. At the same time, the average temperature per day was calculated using the formula:

$$t_{\text{cp}} = \frac{\sum_{i=0}^{n} t}{n} \tag{1}$$

Where t is the temperature value from the sensor at a certain point in time, n is the total number of values in the numerator.

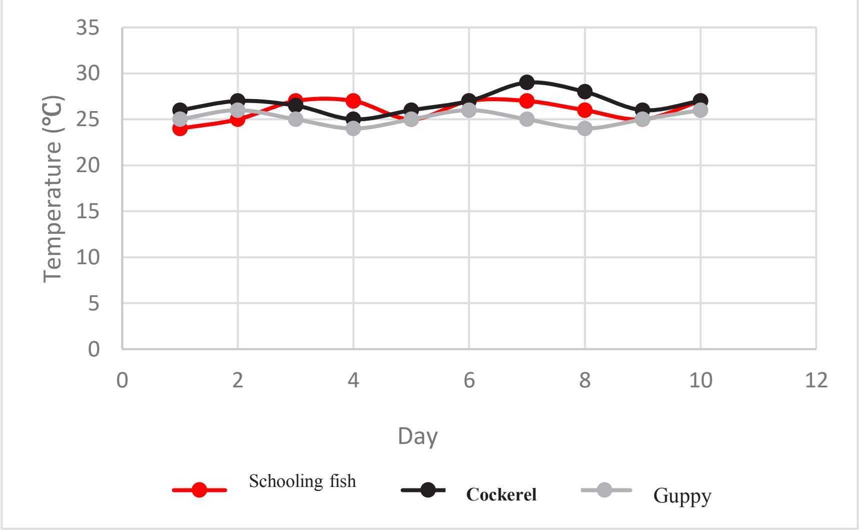

Fig. 9. The temperature characteristic obtained during an experiment with 3 species of fish in an automated aquaponic system

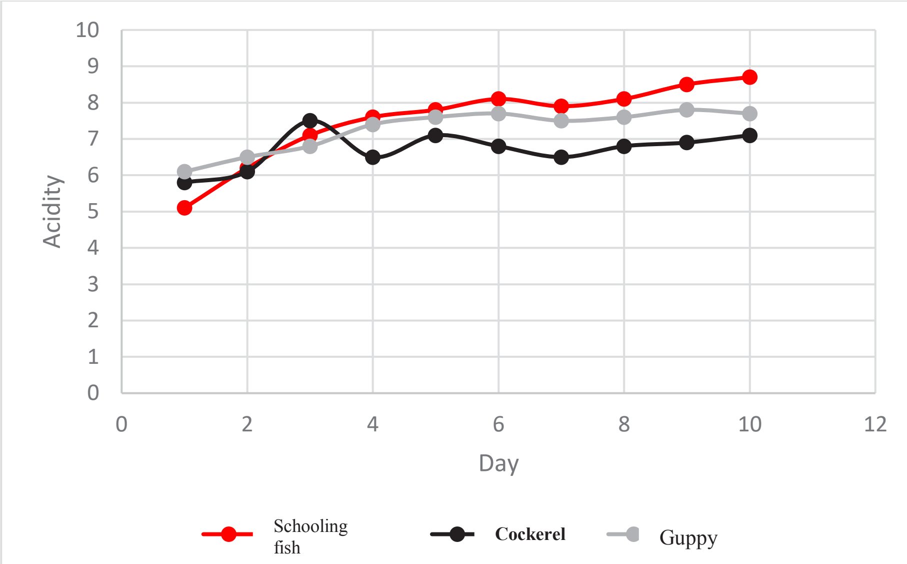

Fig. 10. Acidic (pH) characteristic obtained during an experiment with 3 species of fish in an automated aquaponic system

Within 10 days, the degree of NO3 utilization in the installation with a cockerel and with schooling fish was recorded and evaluated. Throughout the entire plant growth cycle, water was not replaced or refilled. Water purification took place through a pump supplying water from the aquarium to the hydroponic compartment through a built-in sponge filter (in the pump). The results are shown in Figure 11, as can be seen from them, the system has a low degree of NO3 utilization, due to (depends on) this is due to the peculiarities of the micro-greenery culture, the number and type of inhabitants in the aquarium.

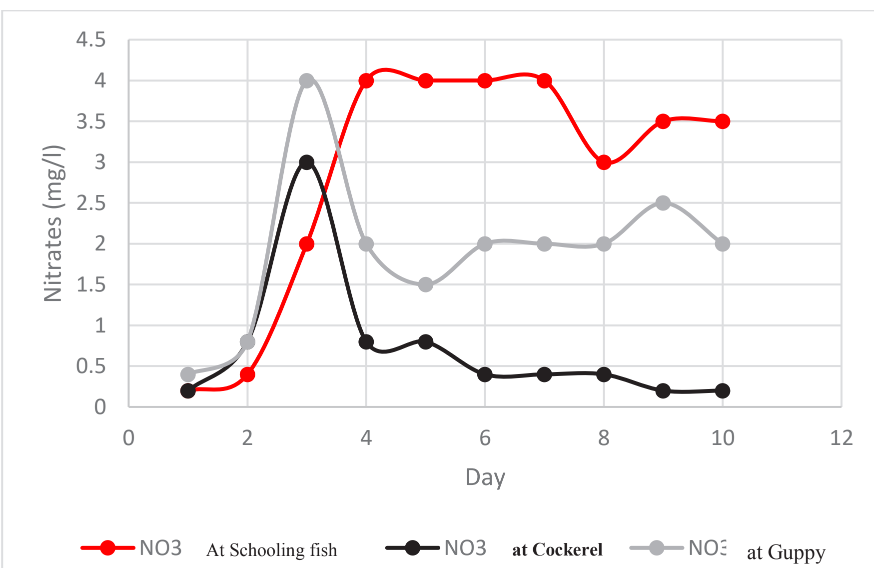

Fig. 11. A graph of the dependence of the concentration of nitrates (NO3) obtained during an experiment with 3 species of fish in an automated aquaponic system

Also, during the entire period of plant growth, the degree of germination of microgreens was recorded, by measuring the length of the average stem of seedlings in a cell using a caliper. The results are presented in table 2.

Table 1. The experimental data obtained on the germination rate of the sown microgrowth in comparison with two types of planting in an aquapon installation and a conventional plastic basket

Boarding:	Aquaferm hydroponics			The basket			Aquaferm roots	
Day	L broccoli	L cabbage	L peas	L broccoli	L cabbage	L peas	L broccoli	L cabbage
1	5	3	0	5	3	0	5	3
2	20	5	0	15	5	0	14	7
3	35	10	2	30	9	5	27	8
4	45	15	10	40	11	11	37	13
5	50	25	35	47	23	25	42	23
6	55	35	53	50	30	31	49	33
7	63	50	60	54	45	51	58	48
8	74	64	83	59	53	45	65	53
9	81	76	111	61	58	51	68	61
10	86	80	150	63	61	60	72	67

Aquaponics is a symbiosis of the existence of artificially bred freshwater animals, hydroponic crops of agricultural plants and colonies that process organic bacterial residues [2]. Vegetables and herbs are grown in containers that do not contain soil, and plants receive their nutrition from wastewater discharged from ponds. Plants feed on bacteria from fish waste products, and then this water is returned back to the pond in a purified form. These systems can be both large and small, depending on the desire and capabilities, and are potentially capable of producing fish and vegetables in large quantities.

The graphical results are shown in Figures 12-14, from which the following conclusions can be drawn:

- germination of microgreens in aquaponics is 8-20% faster than in the usual form, while the percentage depends on the type of crop (including peas, the difference is 68%, while the exact reason could not be established);
- It is more efficient to grow microgreens in an aquafarm with close contact with water than to lift a biodegradable mat to immerse the roots in water, since 15-18% of the germination rate of the crop is lost;

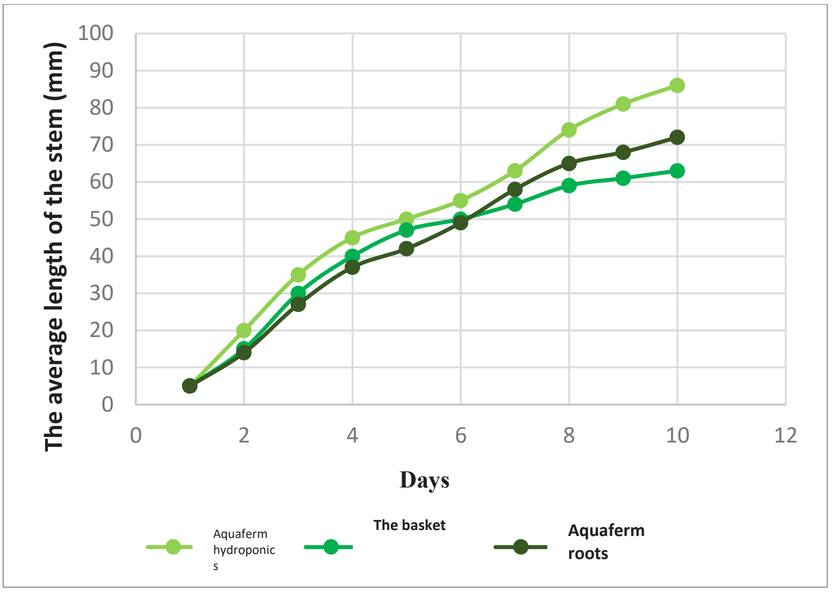

Fig. 12. The germination schedule of the sown micrograin "Broccoli" in comparison with two types of planting in an aquaponic installation and a conventional plastic basket

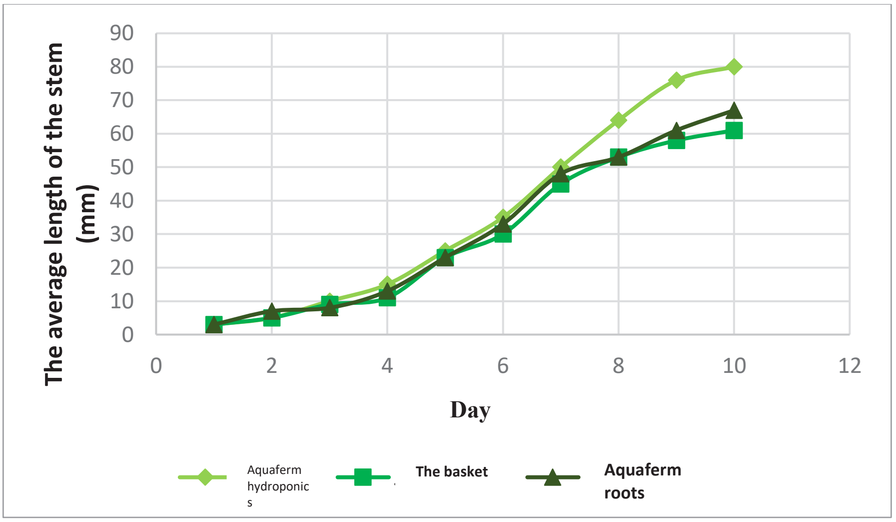

Fig. 13. The germination schedule of the sown microgrowth "Red Cabbage" in comparison with two types of planting in an aquapon installation and a conventional plastic basket

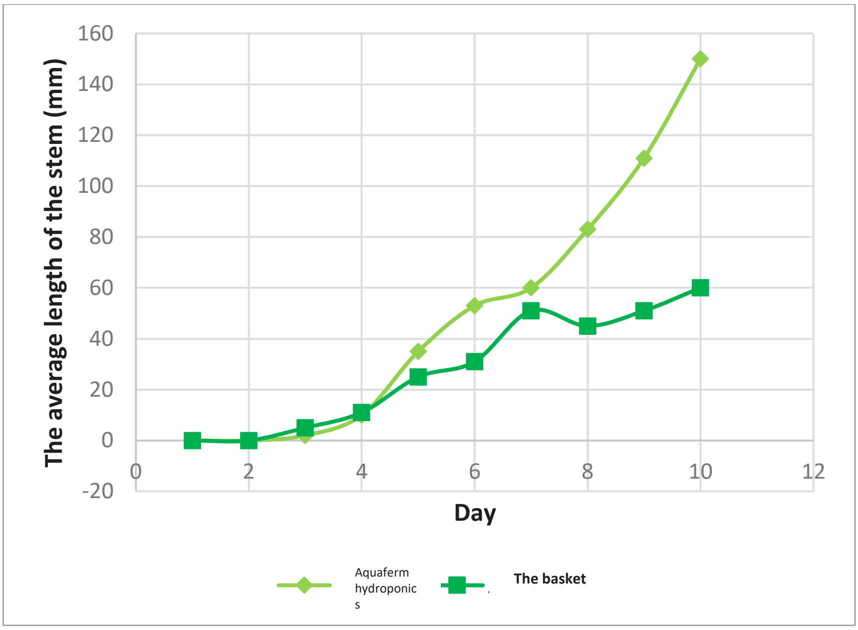

Fig. 14. The germination schedule of the planted microgrowth "Peas" in comparison with two types of planting in an aquapon installation and a conventional plastic basket

7 Conclusions

During the research, an automated system for home cultivation of microgreens using aquaponics technology using modern technologies and a review of literary sources was developed. The researcher was convinced that the automation system of the aquafarm is able to significantly simplify human care of the aquarium.

The advantage of using this system over the "classical" method of growing microgreens, in terms of the rate of ascent of stems, has been experimentally verified. In an automated aquafarm, microgrowth grows faster than in a conventional plastic basket, the average succession is 20%, but this figure depends on several factors: the type of microgrowth seeds, the type and number of inhabitants in the aquarium compartment. And hydroponic planting with constant soaking of micro-green seeds is more effective than hydroponic planting without constant soaking of seeds with immersion of only the roots in water in an automated aquaponic installation.

It can also be said that the developed automated system for a home aquapon installation has a positive effect on the biological ecosystem. Monitoring of the main indicators of water quality has shown sufficient effectiveness of this method to neutralize indicators such as nitrates. The degree of neutralization depends on the type and number of inhabitants in the aquarium compartment, as well as on the frequency of water substitution and refilling. In the future, it is planned to continue experiments for longer periods and monitor a wide range of water quality indicators and the cultivation of more types of seeds.

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