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PROCESSES AND APPARATUSES OF CHEMICAL TECHNOLOGY

Reagent-Free Technology for Intensifying the Process of Growing Microgreens in Aquaponic Systems

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Abstract—An assessment is made of the current state of the global food security, which arises as a result of new challenges, in order to achieve the UN Sustainable Development Goals. Currently, aquaponic technologies are considered quite promising for providing regional consumers with food (hydrobionts and phytoproducts). Reagent-free technologies for intensifying plant growth and development (electromagnetic influence, ultrasonic waves, corona discharge) are analyzed. The use of installations for the electrolysis treatment of aqueous solutions for growing hydrobionts before feeding them into hydroponic modules is substantiated. The results indicate a significant increase in plant productivity by more than 30% after electrochemical treatment. Changes in the hydrochemical and hydrophysical properties of water after electrolysis are analyzed. A scheme of an aquaponic system for intensifying reagent-free electrolysis of growing microgreen plants is proposed and verified. It is substantiated that further research should be aimed at building process-control systems in aquaponic installations and creating specialized energy-efficient DC power supplies.

Keywords: reagent-free technology, aquaponic systems, electrolysis, phytoproducts, hydrobionts, intensification
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INTRODUCTION

Since the beginning of 2019, the global recession caused by the COVID-19 pandemic has deprived women and the most vulnerable and disadvantaged populations, including those in poor urban areas and those working in the informal sector, of their livelihoods, especially in the poorest countries [1]. More than 200 countries and territories have scaled up social welfare measures in a variety of settings, spending about USD 750 billion to mitigate these impacts. A key negative consequence of the economic unrest is the problem of insufficient food supply to the population, which remains a rather urgent issue even in an era where most developed and developing countries do not consider food production a problem: in the United States, Great Britain, Russia, and Israel, *food-tech* projects are even appearing, which reduce the effort spent on buying food to a minimum [2]. However, according to the UN, about one tenth of the world's population is currently undernourished. The situation is extremely aggravated against the backdrop of the current global military-political crisis.

Accordingly, scientific and technological developments aimed at achieving the UN Sustainable Development Goals (Goal 2. Ending Hunger, Ensuring Food Security and Improving Nutrition and Promoting Sustainable Agriculture) have significant global relevance.

The issue of regional food security can be addressed through the implementation of aquaponic installations, in particular in areas where land farming is characterized as "high-risk." Such technological complexes represent an artificial ecosystem in which there are three types of key living organisms: aquatic animals (usually fish), plants, and bacteria.

Such facilities operate according to the synergistic principle: fish provide a nutritional basis for plants, bacteria transform nutrients for flora, and representatives of the latter purify the water [3, 4]. Feeding of aquatic organisms ensures a constant supply of nutrients to the aquaponics system, making the addition of hydroponic nutrient solutions unnecessary. At the same time, in aquaculture, up to 70–75% of the feed is converted to waste in the solid, dissolved, or gaseous form. Consequently, nutrient concentrations in closed recirculation systems with a water consumption of less than 2% can reach levels similar to those in specialized hydroponic feeding solutions.

The purpose of the work is to develop a reagent-free technology for intensifying the cultivation of microgreens in hydroponic systems, which will make it possible to increase the yield per unit area or volume of the equipment without additional contamination of

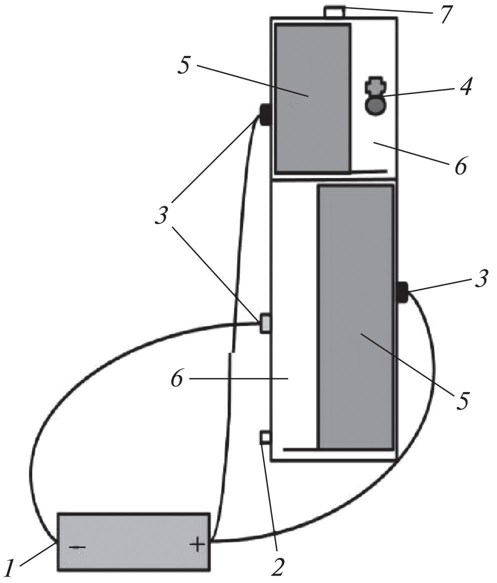

Fig. 1. Schematic view of the electrolysis unit for processing aqueous solution of aquaponic system: (*1*) DC power source; (*2*) inlet tap; (*3*) current leads; (*4*) tap for sampling; (*5*) anode zones; (*6*) cathode zones; (*7*) outlet valve.

the aqueous solutions, thereby increasing the technical and economic indicators of the technological complexes.

ANALYSIS OF STUDIES BY OTHER AUTHORS

In recent years, much attention has been paid to the issue of developing technologies for agent-free and low-waste treatment of wastewater or liquid industrial waste. Methods of physical and physicochemical influence are proposed, which make it possible to reduce the concentrations of polluting components [5–8].

Low germination, high susceptibility of varieties to diseases and pests, weak germination energy of seeds due to their hardness, and insufficient efficiency of the development of nutritional components from various media, including the aquatic environment, are considered to be important reasons hindering the increase in the yield of agricultural crops. In order to efficiently overcome the mentioned shortcomings, it is necessary to use modern highly efficient technologies for the preparation of plants, seed material, and growing media to ensure the elimination of these shortcomings.

Such solutions include electrical complexes that use magnetic devices to change the properties of water, which can be efficiently used in irrigation systems of various agricultural crops [9]. At the same time, the parameters and design of devices for water magnetization have a significant impact on the development and yield of cultivated plants. The study of various options for the use of electromagnets has made it possible to establish advantages in the cultivation of various agricultural crops with an improvement in the final indicators at higher magnetic induction parameters and an increase in the area of action of the magnetic field on the supplied water.

Ultrasonic treatment of grain and seeds before planting intensifies the germination process and increases the yield of various crops by an average of 20–40% [10]. After exposure to ultrasonic waves, barley grains sprout 2–3 days earlier than the reference plantings, the ear length and grain quantity increase by 30%, and the number of stems per grain also increases by 25–30%.

Of great practical and theoretical interest is the presowing treatment of seeds in the electric field of corona discharge [11]. This permits increased plant productivity by improving the sowing qualities of the seed material. Ionization of the surface atoms of ion-exchange substrates enhances the ion-exchange properties and saturates the substrate with electrons necessary for plants to absorb inorganic nutrients. In this case, the electrical charging of ion-exchange substrates is carried out precisely in the field of the corona discharge.

Studies are known on the intensification of anaerobic processing of organic wastes by their preliminary electrolysis treatment with the use of insoluble electrodes [12, 13]. The obtained results have demonstrated the possibility to increase the yield of a given volume of biogas to 40% (with a higher quality of combustible components) using the intensification of biochemical processing of the fermented substrate.

Based on the compactness of the electrolysis treatment units and the relative possibility of full automation of the technological processes, it is reasonable to conduct an experimental study of the electrochemical treatment of the water distribution of aquaponic systems before they enter the hydroponic module for growing microgreens.

EXPERIMENTAL

As part of the research, an experimental diaphragm-free electrolysis module was created, which includes (Fig. 1) an electrode part, electrical peripherals, and shut-off valves.

The role of the electrodes (anode and cathode) was performed by graphite broken in plastic boxes.

Electrical processing mode: 2 Amps (DC), 48 Volts.

Clarium catfish (*Clarias gariepinus*) with an average weight of 35 g was chosen as an object of cultivation, since it is a hydrobiont with finely dispersed excrement, which is difficult to filter. The planting density was 100 kg/m^3. The volume of the fish tank is 80 liters, so the tank was stocked with 8 kg of catfish.

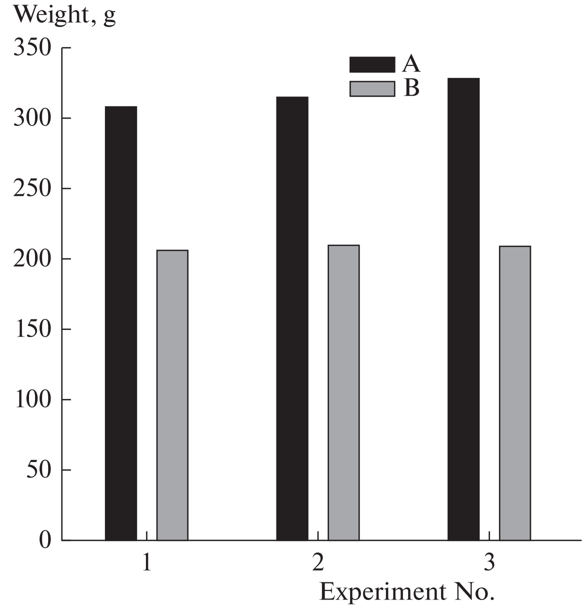

Fig. 2. Comparison of yield for cut plants: (A) with electrolysis treatment of an aqueous solution; (B) without the use of electrolysis treatment.

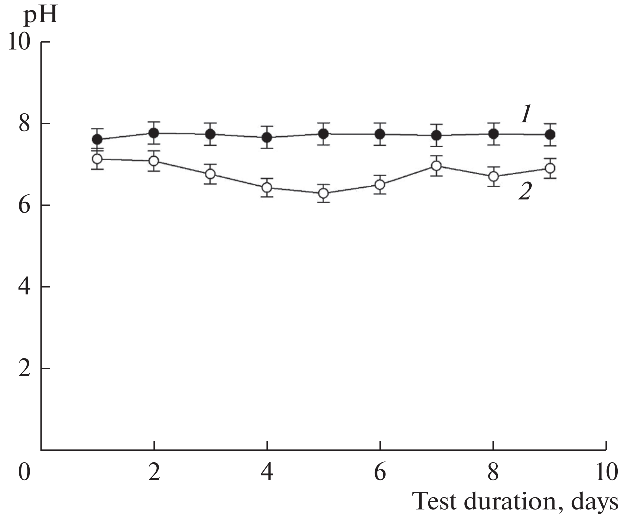

Fig. 3. pH change of aqueous solution of aquaponic system under different methods of mustard cultivation: (*1*) without electrolytic treatment; (*2*) with electrolytic treatment.

Feeding was carried out with compound feed produced by OAO Zhabinka Feed Mill of KO 112-3 grade, with a weight fraction of protein of at least 33%.

In the pilot system, 100 grams of mustard seeds were planted in the hydroponic module of an aquaponic system using NFT (Nutrient Film Technique) technology, with a substrate in the form of a geotextile made of non-woven material. The system used full-spectrum photoluminescent lamps with a power of 18 W. The seeds were in the dark for the first two days, then the lighting cycle was eight hours. A plastic membrane electrolysis cell was connected to the hydroponic module. Electrolysis treatment was carried out for 120 minutes six times a day.

The cultivation cycle from dry seed to finished products of mustard microgreens is nine days, which is how long the experiments were carried out. After ripening, the quality of the greens, the percentage of germination, and the green mass of the product were assessed. The root system was assessed and the geotextiles were checked for the presence of rot and mold.

To carry out hydrochemical control, the aqueous solution was taken from the fish tanks and control was also carried out after electrolysis treatment and passage of the hydroponic module. Next, to assess the influence of electrolysis processes on the aquaponic facility, a control experiment was carried out on the cultivation of Clarias catfish and mustard microgreens, but without the use of an electrolysis unit. The planting density, catfish weight, feed, and cultivation technology were identical; 100 grams of dry mustard seeds were also planted in the hydroponic module and the conditions for growing the phytoproducts were the same. In this system, control over the hydrochemical indicators of the water was carried out from fish tanks and after passing through the hydroponic module.

RESULTS AND DISCUSSION

As a result of the reagent-free electrolysis treatment of the aqueous solution, an increase in mustard yield was recorded: compared to the reference sample, the relative arithmetic mean increase was 34.16% (Fig. 2).

Evaluation of the obtained results clearly demonstrates a significant technological effect. At the same time, the work investigated the dependence of the acidity of the pH environment, redox potential *E*, total mineralization, ammonia/ammonium concentration (NH_3/NH_4^+), and light transmittance on the time of the experiment in comparison with technologies without electrolysis treatment.

Under electrochemical influence, the pH was lower than in the reference sample: the difference reached 1.45 (on the respective days) (Fig. 3).

As for the redox potential, being more negative in the reference sample, it had “more comfortable” values for the plants, and from the seventh day of the experiments it was located in the negative region (Fig. 4).

It is interesting that the total mineralization during the first electrolysis exposure decreases significantly (by 65.4% compared to the reference sample) and then demonstrates a stable linear trend (Fig. 5).

At the same time, monitoring the concentration of ammonia/ammonium (NH_3/NH_4^+) demonstrated its drop to zero during electrolysis treatment with a fur-

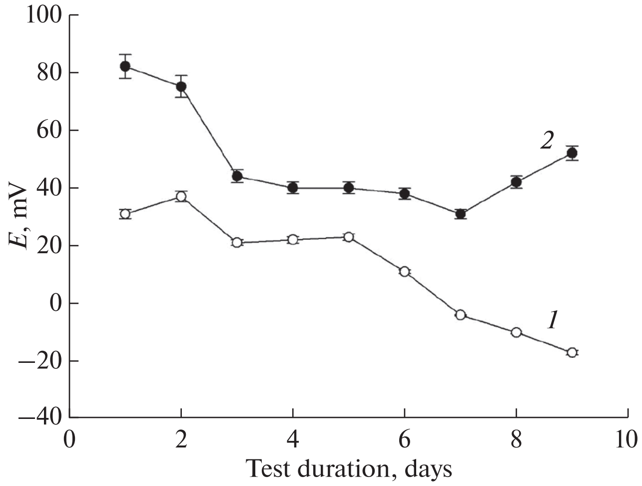

Fig. 4. Change in the redox potential *E* of aqueous solution of aquaponic system under different methods of mustard cultivation: (*1*) without electrolytic treatment; (*2*) with electrolytic treatment.

ther slight increase, with stabilization on the sixth day of the research at values of 2 mg/L; at the same time, in the reference sample there was a systemic increase in this indicator to 7 mg/L (Fig. 6).

Based on the data of Figs. 3–6, it can be concluded that a significant effect on mustard growth was achieved due to the following factors:

— stabilization of the pH of the solution (see Fig. 3). It is known that the optimum value for cultivating plants is a slightly acidic reaction of the medium, equal to about 6.5; at such values, the availability of various nutrients and mineral elements increases, which leads to more intensive plant growth;

— maintaining positive *ORP* values (see Fig. 4). A solution with oxidizing properties in combination with a slightly acidic reaction of the medium contributes to the efficient conversion of nitrogenous compounds, as well as organic products of fish metabolism, into a form more accessible to plants. This fact is evidenced by the reduction in the total mineralization of the solution (see Fig. 5) during electrolysis treatment; this indicates the efficiency of the removal of mineral salts by plants in an accessible form from the solution, which is also confirmed by the decrease in the concentration of ammonia/ammonium in the solution (see Fig. 6).

Evaluation of the organoleptic indicator of an aqueous solution “Light transmittance” in an aqueous environment after electrolysis demonstrates its stabilization at a level of 77–78%. At the same time, in the reference sample there is a constant drop to 33.2% and the aqueous solution turns into a cloudy substrate (Fig. 7).

Accordingly, based on the justified technological efficiency of the reagent-free electrolysis treatment of an aqueous solution, the following arrangement of an aquaponic system can be proposed (Fig. 8).

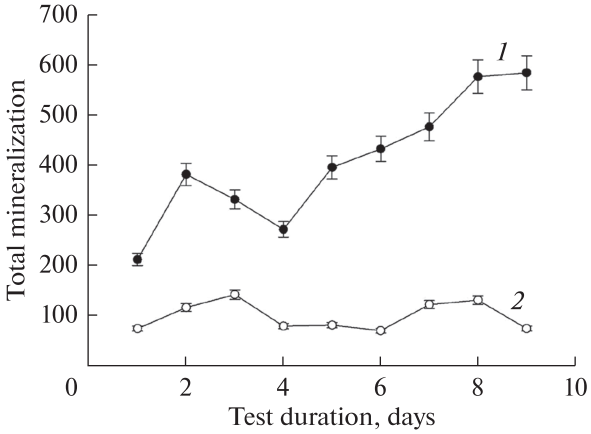

Fig. 5. Change in the total mineralization of aqueous solution of aquaponic system under different methods of mustard cultivation: (*1*) without electrolytic treatment; (*2*) with electrolytic treatment.

Such arrangement includes the following elements: hydraulic supply (tanks, pump, water supply trays); a module for physical purification of the aqueous solution (mechanical filtration, settling tank, floating unit); a module for electrochemical intensification of the growing microgreens (DC power supply, electrolysis cell), with an integrated control unit [14]; and a hydroponic plant-cultivation module.

At the same time, the incremental costs for the electrochemical processes will amount to up to 40% of the energy costs for the operation of the pumping equipment, which is compensated several times over by the increased yield of the phytoproducts.

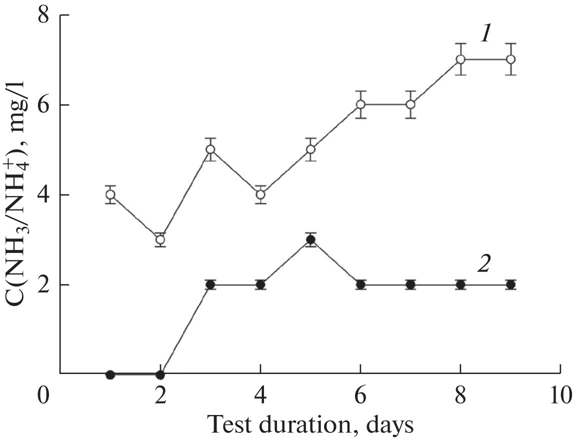

Fig. 6. Change in ammonia/ammonium concentration (NH_3/NH_4^+) of aqueous solution of aquaponic system under different methods of mustard cultivation: (*1*) without electrolytic treatment; (*2*) with electrolytic treatment.

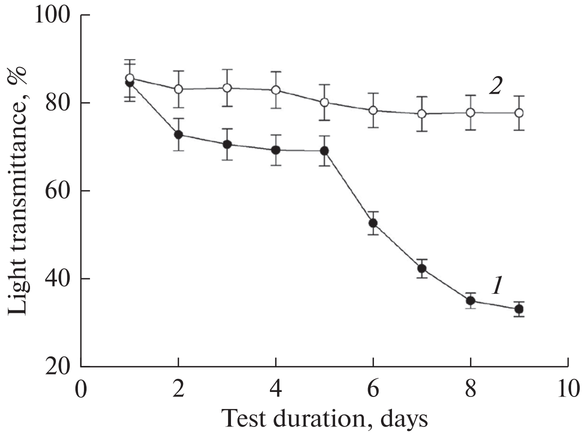

Fig. 7. Changes in the light transmittance of aqueous solution of aquaponic system under different methods of mustard cultivation: (*1*) without electrolytic treatment; (*2*) with electrolytic treatment.

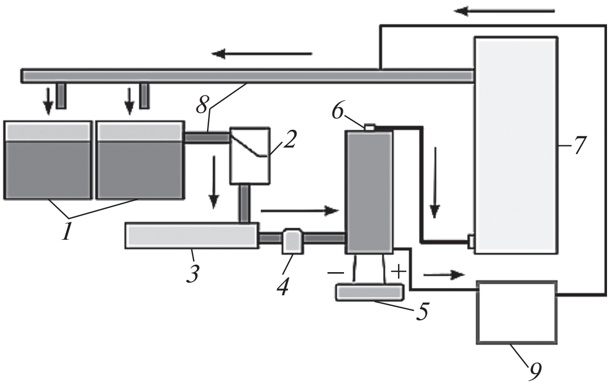

Fig. 8. Schematic view of an aquaponic system with reagent-free electrolysis intensification of growing microgreens: (*1*) fish tanks; (*2*) mechanical filtration system; (*3*) settling tank; (*4*) pump; (*5*) DC power supply; (*6*) electrolysis cell; (*7*) flotation unit; (*8*) water-supply trays; (*9*) hydroponic module.

CONCLUSIONS

It has been established that reagent-free electrolysis treatment of an aqueous solution in aquaponic systems is a promising intensifying technological method. A reagent-free technology has been developed to intensify the process of growing microgreens in hydroponic systems, which allows increasing their productivity without additional contamination of the aqueous solutions, which is confirmed by experimental studies, as a result of which an increase in mustard yield by 34.16% was recorded. It has been proposed to use electrochemical units for upgrading facilities for the production of hydrobionts and phytoproducts, placing them in front of the hydroponic module.

It is reasonable to focus further research on the construction of process-control systems in aquaponic installations and the creation of specialized energy-efficient direct-current power sources.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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