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Technological Project for Vertical Aquaculture Production

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Abstract. **In this report, a technological project is proposed for an ecological greenhouse designed for the cultivation of leafy vegetables, root fruits, spices and aquaculture based on aquaponics. The cycle of sowing, growing, picking the finished product, packaging and shipping is isolated from the external environment and the technology implies optimization of energy resources, seed material, production costs, etc. This ecosystem is innovating the vertical farming industry with high-tech control systems to produce quality and clean produce, reducing costs and making it an attractive option for farmers today.**

Keywords: aquaponics, control, ecological technology, project, vertical farm

I. INTRODUCTION

According to United Nations (UN) forecasts, the population of the planet by 2050 will increase by about 2.5 billion inhabitants. In order to provide food, housing and infrastructure for the growing number of inhabitants, qualitatively new technologies will be needed.

About 80% of the land on the planet, on which food products can be grown (vegetables, fruits, grain, meat, dairy products, etc.), is actively cultivated. The remaining 20% of potential arable land will not be sufficient under existing technologies to feed the growing population of the earth. One possibility to solve this problem is vertical urban farms for the production of vegetables and fruits based on aquaponics, using LED lighting with a specific wavelength to intensify the growth of crops.

They are built where the consumers of the produce (vegetables and fruits) are located, and in a small area on many floors (racks) year-round produce is produced with artificially created parameters: light, nutrient medium, temperature, humidity, ventilation, etc. In this way, the annual production from a unit of built-up area can be increased tens of times, with a significant reduction in the cost of production and a guaranteed daily supply of fresh vegetables and fruits with almost zero transport costs.

Vertical aquaculture production is part of the modern intelligent, innovative and sustainable industry in Bulgaria. [1,2,3] This is an alternative approach to growing vegetables in urban settings.

II. MATERIALS AND METHODS

A. Literature review

Leafy greens such as lettuce, cabbage, spinach and arugula are some of the most popular crops grown in vertical farms. These crops are well suited to the controlled environment of vertical farms, allowing growers to precisely regulate temperature, light and humidity levels. Growing leafy greens in a vertical farm also helps reduce the risk of pests and diseases, which can be a significant problem with traditional outdoor growing. [6]

The greenhouse is designed for growing root fruits and vegetables using ecological technology. The cycle of sowing, growing, picking the finished product, packaging and shipping is isolated from the external environment and the technology implies optimization of energy resources, seed material, production costs, etc. Cultivation is carried out in a relatively sterile environment. For this purpose, all incoming flows (raw materials, work personnel, etc.) pass through a disinfecting and deworming section before entering the work space. This guarantees an ecological product that does not need to undergo additional treatment before use.

The greenhouse differs from the ones known so far due to the specific illumination of the cultivated crops, provided by LED strips with a precisely defined spectrum of radiation and a strictly fixed duration of illumination, related to the biological life cycle of the cultivated plants. (Fig. 2).

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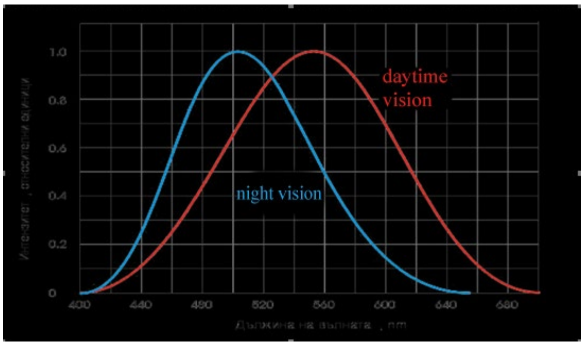

Fig. 1. Human visible wavelength

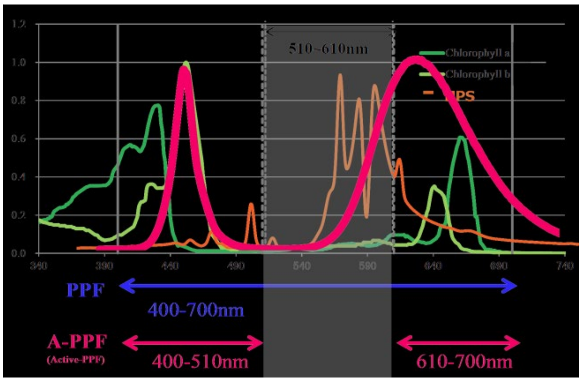

Fig. 2. A necessary absorption spectrum for plant development

Another feature is the biological solution used, which provides the nutritional environment for the plants. A special streamlined system, whose parameters and values are monitored online, allows to guarantee the desired quality and growth rate of the crops. The chemical and biological analysis of the food environment is the basis for the management of technological regimes. The interior of the greenhouse is air-conditioned, with the desired humidity, room temperatures, O_2, and CO_2 content regulated with high precision.

The greenhouse is of a closed type (without external windows) and specific entrance sections to reduce the influence of the environment on the climate (humidity, temperature, air composition) and growing conditions (desired technological parameters and dimensions) of the respective crop, ensuring year-round predictable yields, without seasonal differences. This flexibility allows the replacement of cultivated crops with ones with a higher added value and sales price compared to the season - kopf salad, basil, arugula, etc.

Due to the high automation of the processes, the number of personnel is very small. The greenhouse is adapted to work in different climatic conditions: temperatures from -300º C to +550º C; humidity from 40% to 90%; rain, snow, etc. Its electrical supply is planned to be provided by the electrical distribution network of the area, by solar panels (in the case of autonomous power supply) or by both sources. Water is supplied from the municipal water supply network.

The greenhouse consists of the following separate rooms:

- Room "Laboratory and seed storage";
- Room "Preparation of seedlings";
- "Product growth" room, in which tubs are located for the 3 phases of production growth (Storage III - VI);
- "Packaging and forwarding" premises with the following departments (zones):

- Zone for cutting the roots;
- "Package" Zone;
- "Finished product buffer storage" area

- Premises "Zone for transplanting plants from SP(196), from SP(196) to SP(81) and from SP(81) to SP(36)";
- Room "Disinfection and preparation of plates for reuse";
- "Electrical and technological equipment" room
- Service rooms - changing rooms and WC
- Warehouse "Seeds and Laboratory".

The dimensions of the grow room are as follows:

– Length: 29 m;
– Width: 12 m;
– Height: 2.4 – 2.6 m

The purpose of the individual rooms is related to the growing technology of the particular plant.

B. Methodology of the research

Lettuce growing technology

Seeds, buckets and some of the materials needed for sowing are accepted in the "Seed Storage" room, and the chemical-biological laboratory is also located there, where the parameters of the technological flows and the characteristics of the materials are monitored.

In the "Sowing" room, disinfected styrofoam plates are delivered from the warehouse, into the openings of which the plastic buckets for the preparation of seedlings are placed.

The buckets are cone-shaped. The bottom is mesh with holes through which the seedling nutrient liquid seeps. At this time, open the mesh so selected that the zeolite granules do not fall into the water channel.

The buckets are filled up to 2/3 of the volume with granular zeolite, after which they are supplemented with 1÷1,5 centimeters of volcanic mineral sand. The lettuce seed is placed in the middle of the bucket and with light pressure it is buried to about 0,5 cm below the surface in the volcanic mineral sand.

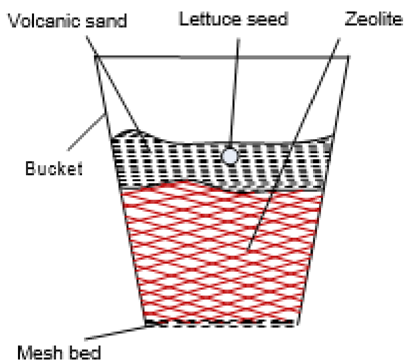

Fig.3. Bucket with seedlings

The buckets prepared with seedlings are placed in the holes of the styrofoam plates, as shown in Figure 4:

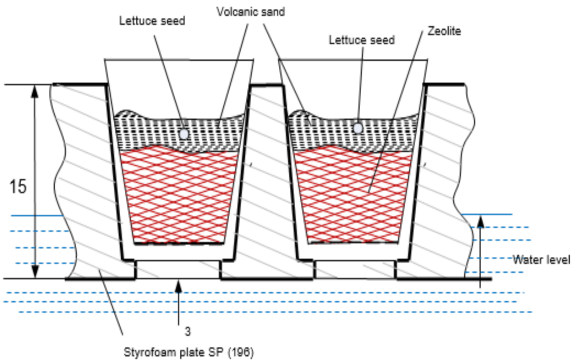

Fig.4. Placing the buckets in the styrofoam plates

The number of the styrofoam plate is related to the number of buckets that can be placed in the holes of the given plate (in this case 196 pcs. - square 14 by 14 buckets).

The operations in this department: placing buckets in the holes of the styrofoam plates and filling them with zeolite, volcanic sand and lettuce seeds are done by hand. The working staff also passes through this room. The input streams are separated and do not cross.

After the styrofoam plates prepared with seedlings have passed through the seeding room, they enter the next room. A tub made of artificial material with a depth of 20 cm and a slight slope in the direction of the technological flow is installed on each shelf.

In view of the height of the room of 2.6 m and the presence of girders, reducing the height to 2.4 m, it is planned to have 3 floors for each rack. The distance between the tubs is 60 cm. LEDs are installed on the underside of the tubs, which provide the necessary light for the growth of the plants. A nutrient solution flows in the tub, the level of which is 10 cm. The system for distributing the nutrient solution to the tub, as well as the air conditioning ducts, are located in the light opening between the tubs.

Styrofoam plates SP (196) with the prepared seedlings in buckets are placed in them, which are pushed every day from right to left, freeing up space for the newly sown plates. The size of these plates is 1 meter X 1 meter, and the styrofoam has sockets with a wide opening at the base through which the aqueous solution penetrates into the zeolite bucket, as shown in Figure 5.

The climate parameters in the "Production growth" room are: the daytime temperature is maintained at 230^o C, and the night temperature at -200 ^{o}C. The duration of the day is 16 hours, and the night is 8 hours. The light intensity of the lettuce in the different phases of growth is different. In the baths, in one direction, flows a biological solution, which is pumped from a buffer recirculation tank. To preserve the intensity of the nutrient medium, the biological solution is fed to several places along the bath.

The racks have a minimum slope of 1 in 1000 to allow for slow movement of the aqueous solution from one end of the bath to the other and to move the styrofoam plates to the outlet of the aftertreatment baths. The aqueous solution that flows from the end of the baths is collected in a recirculation tank.

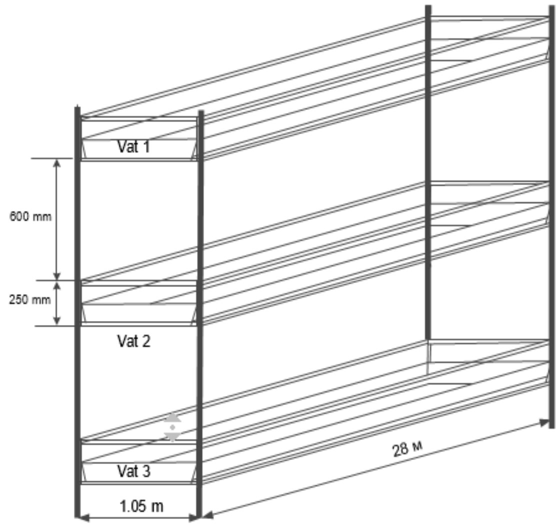

Fig.5. Rack with shelves in the "Produce Growth" room

The lighting of the plants is carried out by LED lighting fixtures with a certain intensity and radiation spectrum, located directly above the styrofoam plates. The conducted experiments and calculations have allowed to determine the most effective lighting, the spectrum, intensity and duration of which stimulate the maximum growth and provide a minimum of dissipated thermal energy that affects the climatic parameters.

Processes in the grow room are realized automatically. For this purpose, the following automated systems have been designed and built:

- Access control system with automatic scanning of access conditions (chip, card, fingerprint, pass sensors);
- Climatic system for control and management of the climate in the room;
- Lighting system to ensure the proper lighting of the vegetation and separately of the working premises;
- A pumping station that manages the water flows from the fish pond to the greenhouse and its water troughs and vice versa - from the greenhouse to the fish pond;
- System for controlling the parameters of the nutrient aqueous solution.

In the "Packaging and forwarding" room, the lettuces grown up to 200 grams and measuring 16.7/16.7/22 cm are removed from the styrofoam plates SP(36), their roots are cut off, keeping a minimal root system in order to preserve the freshness of the lettuces . Empty styrofoam plates and buckets are sent to the "Disinfection and preparation of plates for reuse" room.

In the packaging department, the lettuces are placed in individual packaging (slightly perforated antibacterial cellophane). 20 (5*4) pieces of lettuce are placed in a corrugated cardboard package with dimensions of 80/60/23 cm, and in this way the lettuce is slightly shrunk through the cellophane packaging. The cleanliness of this room determines the biologically clean nature of the finished product.

For the second stage of development of the greenhouse project, additional cultivation of aquaculture (tilapia, rainbow trout) is envisaged, the symbiotic existence allowing the minimization of nutrient solution costs for hydroponic cultures on the one hand and the absence of the need to purify the water environment for fish.

The fish tank room (stage 2) is a key node in the technological process and converts the technology from hydro to aquaponics. The method of building a farm for the combined cultivation of plants (agricultural crops) and fish in an interconnected cycle (mutual exchange) has been known since ancient times.

The name "aquaponics" was proposed by scientists from the University of the Virgin Islands as a result of years of research. This name reflects the combination of two progressive technologies: "hydroponics" - growing plants not in soil, but in a water environment, and "aquaculture" - growing fish, crabs, shrimps, mussels, etc. in a well organized system. [4]

Broadly speaking, aquaponics is the combined cultivation of fish and plants in a circulating ecosystem by using natural bacterial cycles to convert the waste created by the fish into nutrients for the plants.

The main products of the microbiological decomposition of the waste from the farmed fish are ammonia released and dissolved in the water, which under the influence of aerobic bacteria and oxygen dissolved in the water lead to the oxidation of ammonia and its gaseous derivatives - amines (ammonium compounds [R4N] +CI - , aliphatic CH3-N<, aromatic C6H5-N<, etc.) with the formation of nitrites (salts of nitric acid, such as sodium nitrite $NaNO_2$) and nitrates - "nitric acid" salts of nitric acid HNO_3 , such as ammonium nitrate $NH4NO_3$). This reduces the chemical toxicity of the fish rearing water and allows the plants to absorb the nitrate compounds needed for their growth.

Plants directly absorb ammonia from the water and dissolved salts much more naturally. In this case, the bioremediation process is used: the colonies of bacteria in the substrate and the root system of the plants in a closed cycle of aquaculture, purify the water from toxic substances, and the plants absorb the salts, gases and chemical elements dissolved in the water: nitrates, nitrogen, phosphorus, carbon dioxide and to some extent enrich the water with oxygen, which returns to the pool with the fish in a purified form.

Fertilizer for plants is also detritus - the solid waste from fish in the aquaponics system. Settlers and a system of mechanical filters are used to clean the water of solid waste and suspended particles. Denitrification in "aquaponics" is carried out naturally - a balanced activity of plants and bacteria, and only in extreme cases additional cleaning with expensive carbon filters is necessary.

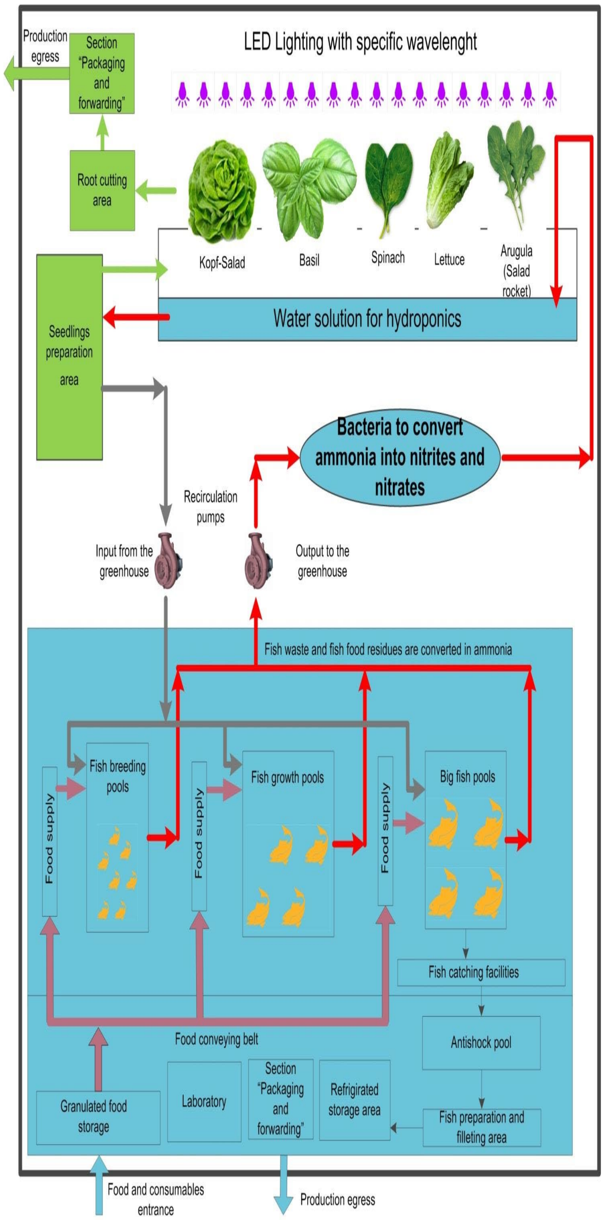

Fig. 6. Technological scheme of aquaponics

A number of observations, and subsequently experiments, have shown that plants can be grown only in a water environment, without the need for soil. At the same time, if fish are grown in the aquatic environment, a double effect occurs. The wastes of fish farming and growth prove to be a suitable nutrient medium for plants immersed in the aquatic environment. In turn, the plants are an excellent filter, as the waste matter from the fish is deposited on their roots, thus purifying the water in the pool. Plants feed on the products released by living organisms (potassium, nitrogen and phosphorus compounds, carbon dioxide, etc.) and naturally purify and enrich the water environment with oxygen. The production process eliminates the need to use chemical fertilizers and the need for their dosing and soil treatment. The chemical process of processing and purification is carried out naturally in a closed cycle and does not require the use of synthetic chemicals.

Aquaponics mimics the natural water cycle in nature. [5] The symbiosis between the cultivation of plants and fish in a common aquatic environment unexpectedly leads to the intensification of plant and fish growth, resulting in a closed ecosystem.

Fig. 7. Vertical cultivation in urban conditions

III. RESULTS AND DISCUSSION

The process of producing plants and fish at the same time in such a farm turns out to be ecologically clean, since the biological balance is delicate and any drastic deviations lead to the failure of the plant crop or the death of the growing fish.

In this sense, it can be argued that the fish feed the plants, and the plants protect the aquatic environment in which the fish are raised by removing the substances that negatively affect the farmed fish. Regardless, it turns out that a combined cycle of plant and fish farming is always more efficient than separate farming and yields a greater amount of marketable plant and fish production.

Another characteristic feature of hydroponics (an integral part of aquaponics) is that the cultivation of plants does not require land and its cultivation, and the plants grow in a water environment. This enables the development of the greenhouse in a vertical direction, with the plants themselves being grown in vertically arranged water channels. In this way, a much larger amount of produce is grown per unit of land area (up to 10 times more). Fertilizer for plants is also detritus - the solid waste from fish in the aquaponics system.

Settlers and a system of mechanical filters are used to clean the water of solid waste and suspended particles. Denitrification in "aquaponics" is carried out naturally - a balanced activity of plants and bacteria, and only in extreme cases additional cleaning with expensive carbon filters is necessary.

Of utmost importance for the growth of plants and fish is the pH value of the water environment, which depends on the specific plants and fish, but is generally maintained around 7. Respiration, complete nutrition of the fish and denitrification require a sufficient amount of dissolved oxygen in the water , therefore the water is aerated. Carbon dioxide, as a product of respiration, must be effectively removed from the system either naturally or by filtration

The constant parameters of the water environment have a beneficial effect on the cultivation of fish and plants. For example, a temperature of around 15º-16º C is most suitable for growing cold-loving fish - salmon and trout. These are well known in the market - Atlantic salmon, salmon trout and rainbow trout. The parameters of the fish breeding room are: length – 20 m; width - 10 m and height - 4 m. The pools are divided into small fish breeding areas; raising the fish until they grow up to 10-15 cm and an area for raising fish up to a size of 30-40 cm.

The individual zones in the fish breeding compartment are built from modules, the size of which is typified and determined by the type of fish grown and the amount of desired final catch per day.

The modular construction of the fish breeding room allows different types of fish to be bred and grown in parallel in the individual modular pools, depending on the needs of the market. It is permissible to mix different populations if there is a possibility of non-conflict coexistence.

IV. RECOMMENDATIONS

Such a system can be built in a standard greenhouse, outside in the garden, in closed rooms (garages, warehouses, underground rooms) with the addition of special LED lighting.

The eco-friendly aquaponic innovation technology makes it possible to create fish farms in a variety of places, for example in buildings or on city rooftops. Home production of useful foods without much effort becomes quite possible. This ecosystem also finds a hobby application, at home or in the office, the fish tank can be combined with a mini garden for growing herbs, fruits, vegetables or flowers. Aquaponics can also be used for educational and research purposes or for agritourism.

V. CONCLUSION

In the modern age, aquaponics is the garden of the future, because we are in it, but it is also in us - in our home, in the office, everywhere. This new integrated system can provide both fish and crop plants while using minimal resources. The proposed ecological greenhouse proves to be a reliable, sustainable and exciting method of growing food due to its following advantages:

- The lowest production price of lettuce, as with competing technologies, the price of lettuce is about 25% higher.
- The lowest investment for the production of 1 lettuce per day, while with competitive technologies the investment is about 30% higher.
- Lowest energy costs for the production of one lettuce - about 25% lower costs compared to the best achievements.
- As a result of the aquaponic production, the production receives a "bio-certificate", and the water used is reduced by up to 95%.

The developed technological project for vertical aquaculture production is suitable for people who do not have access to traditional agriculture.

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REFERENCES

[1] D. Petrova, Intelligent, Innovative and Sustainable Industry in Bulgaria – prospects and challenges, Vide I. Tehnologija. Resursi - Environment, Technology, Resources, Proceeding of the 12th International Scientific and Practical Conference „Environment. Technology. Resources“, June 20-22, 2019, Rezekne, Latvia, Volume I, pp. 210-215, ISSN 1691-5402 – print, ISSN 2256-070X – online. https://doi.org/10.17770/etr2019vol1.4188

[2] D.Petrova, An Alternative Approach to Reducing Aging of Innovative Industrial Products in Terms of Industry 4.0, Environment. Technology. Recourses – Proceeding of the 13-th International Scientific and Practical Conference, Rezekne Academy of Technologies, Rezekne, Latvia, 2021, ISSN 1691-5402, Online ISSN 2256-070X, https://doi.org/10.17770/etr2021vol3.6507 p. 274-280, scopus

[3] D. Petrova, An Approach to Modeling Innovation Obsolescence, Vide. Tehnologija. Resursi - Environment, Technology, Resources, Proceeding of the 14th International Scientific and Practical Conference, 2023, Volume I, pp. 175–179, Print ISSN 1691-5402, Online ISSN 2256-070X, DOI:https://doi.org/10.17770/etr2023vol1.7237 , https://www.scopus.com/authid/detail.uri?authorId=56323816400W.-K. Chen, Linear Networks and Systems. Belmont, CA: Wadsworth, 1993, pp. 123-135

[4] [Online]. Available: https://agri.bg/novini/sho-e-to-akvaponika [Accessed: Febr. 10, 2024].

[5] [Online]. Available: https://www.bgaquaponics.bg/aquaponics[Accessed: Febr. 14, 2024].

[6] Crops Grown In Vertical Farming .[Online]. Available: 6https://bg.tenleadpf.com/plant-growing-cube/hydroponic-growing-cube/crops-grown-in-vertical-farming.html [Accessed: Febr. 20, 2024].