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CURRENT STAGE OF AQUAPONIC SYSTEMS

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Abstract: Aquaponics combines hydroponics and recirculating aquaculture elements. Conventional hydroponics requires mineral fertilizers to provide plants with the necessary nutrients, but aquaponics systems use available fish water, rich in fish waste, as nutrients for plant growth. Another advantage of these combinations is that excess nutrients do not have to be removed by periodic exchange of freshwater enrichment, as is practiced in aquaculture systems. The system results in a symbiosis between fish, microorganisms and plants and encourages the sustainable use of water and nutrients, including their recycling. Within this synergistic interaction, the respective ecological weaknesses of aquaculture and hydroponics are turned into strengths. This combination substantially minimizes the need for nutrient input and waste removal, unlike when they are used as separate systems, so in the article we have a presentation of the evolution of aquaponic systems.
Keywords: aquaculture, sustainability, common fisheries policies, environmental policies

1. INTRODUCTION

Aquaponics is the technology that refers to combining aquaculture (cultivation of aquatic organisms) and hydroponics (soilless cultivation of plants) in a system where nutrient–rich water from aquaculture is used as fertilizer for cultivated plants.

An agricultural culture system based on the aquatic environment, in which the metabolic products, resulting from the growth of fish or other aquatic animals, provide nutrients for the growth of plants in the hydroponic system, plants that in turn purify the water that returns, clean, to the basins with fish. In short, a combination of aquaculture and hydroponics.

The first iterations of the aquaponic concept appeared in the 1970's and 1980's but without using the term "aquaponics". It referred to "combined production of fish and vegetables in greenhouses" or "combined production of fish and plants", in recirculating water (*Naegel, LCA., 1977, Rennert, B, et al., 1989, Sneed K., 1975*). With the appearance of the Aquaponics Journal in 1997, the term aquaponics was used as a general one, although other terms remained in use, such as "integrated fish/vegetable co–culture system" (*McMurtry, MR. et al, 1997*). As can be seen in figure 1, aquaponics has gained more popularity in the last two decades. The 4 main components of an aquaponic system are:

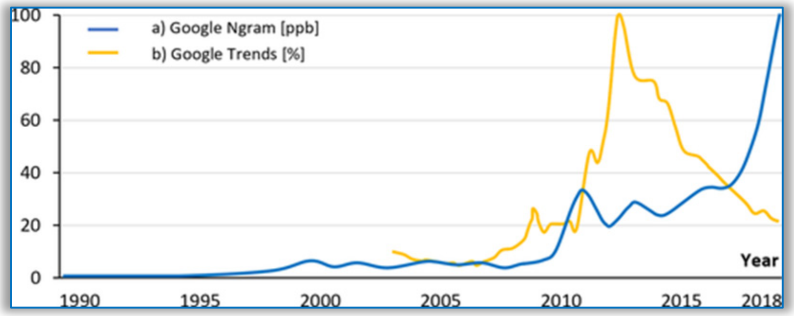

Figure 1 – The Rise of Aquaponics in (a) Google Ngram and (b) Google Trends (Kloas, W.et al, 2020)

1. A biomass converter – tank where fish/aquatic species are grown.
2. A waste processor – Takes water and filters out solid waste (fish excrement and any uneaten food) ~40% of the carbon supplied in the feed is separated as 'sludge'.
3. An aerobic converter – A bio–filter that incorporates bacteria to oxidize ammonia (which is toxic) to nitrates that plant systems can use.
4. A phototrophic converter (vegetable biomass) – beds to grow plants that take nutrients from fish waste and stabilize and purify the water that is recycled. (*David, C. et al, 2021*).

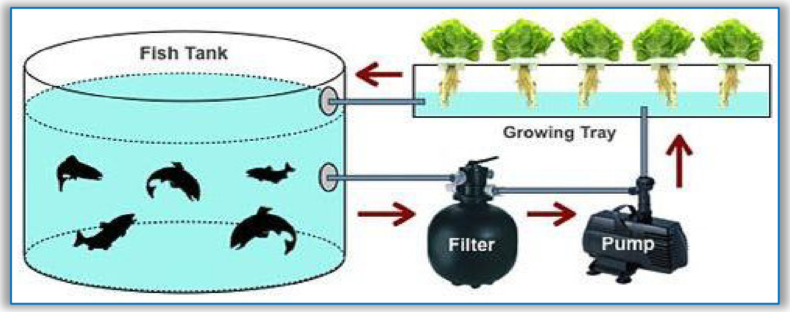

Figure 2 – Aquaponic system (David, C. et al, 2021)

Fish generate ammonia as a result of the feeding process. The use of a biological or even mechanical filter has the role of transforming ammonia into nitrates, useful for plants. This is due to the fact that nitrifying bacteria are found in the biological filter. The secret lies in nitrates, which are absorbed by plants and are important in the process of plant nutrition and growth. The water that comes from the bottom of the fish passes to the root of the plants or fruits, thus the plants absorb the nutrients they need to grow. Aquaponics combines hydroponics and recirculating aquaculture elements. Conventional hydroponics requires mineral fertilizers to provide the plants with the necessary nutrients, but aquaponics systems use the water available from fish, rich in fish waste, as nutrients for plant growth. Another advantage of this combination is that excess nutrients do not have to be removed by periodically exchanging fish–enriched water with fresh water, as is practiced in aquaculture systems. The system results in a symbiosis between fish, microorganisms and plants and encourages the sustainable use of water and nutrients, including their recycling. Within this synergistic interaction, the respective ecological weaknesses of aquaculture and hydroponics are turned into strengths. This combination substantially minimizes the need for nutrient input and waste removal compared to when used as separate systems.

Plants require macronutrients (eg H, C, O, N, P, K, Ca, S and Mg) and micronutrients (eg Mn, Fe, Cl, B, Zn, Cu and Mo), which are essential for their growth.

Aquaponic systems must be able to host different communities of microorganisms that are involved in the processing and solubilization of fish waste. Ammonia ($NH4+$) in fish urine and gill excretion can reach toxic levels if not removed from the system. This can be done by gradual microbial conversion to nitrate. One of the most important microbial components is the consortium of autotrophic nitrifying bacteria that settles as a biofilm on solid surfaces in the system and is mainly composed of nitro–bacteria (e.g. Nitrosomonas sp.) and nitro–bacteria (e.g. Nitrospira sp., Nitrobacter sp.). Ammonia in the system is converted to nitrite ($NO2-$) by nitro–bacteria, before being converted to nitrate ($NO3-$) by nitro–bacteria. The end product of this bacterial conversion, nitrate, is considerably less toxic to fish and, due to its bioconversion, is the main source of nitrogen for plant growth in aquaponic systems. In most systems, a special biofiltration unit is required where intensive nitrification takes place, (*Goddek, S. et al, 2015*).

The approach to measuring recurring parameters may vary from system to system. For example, the water pH detection system can range from pH test strips, some stand–alone sensors with an attached LCD screen, or analog sensors capable of transmitting information, wirelessly or not, to a controller (PLC, microcontroller etc.). In order to design a reliable, durable and economically feasible system, automatic detection techniques must be evaluated. Monitoring and controlling the environment and equipment through intelligent technology is the premise and foundation to ensure the stable operation of the aquaponics system. Over the years, various types of aquaponic systems have been proposed, adopted and explained, mainly classified as coupled and decoupled systems. (*Yanes, A.R., et al, 2020*).

2. MATERIAL AND METHOD

Figure 3 shows an example of a classic coupled aquaponic system (CAS), the UVI (University of the Virgin Islands) aquaponic system. The CAS consists of a continuous loop system, where the water has only one direction or outlet in each tank. Figure 5 shows a decoupled aquaponic system (DAS)

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that uses sub–loops within the system where water can travel in more than one direction in some tanks. This is primarily for superior filtration and an increased ability to handle the nutrient concentrations and pH of the water in the system.

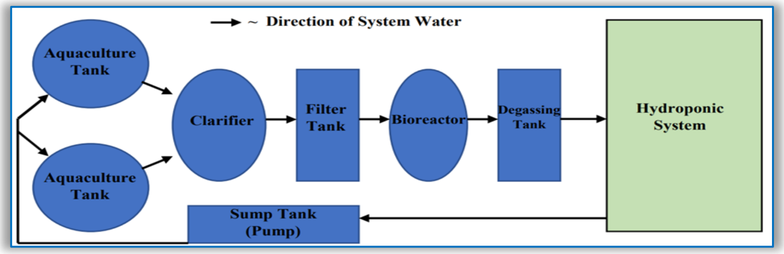

Figure 3 – Example of a coupled aquaponic system (Yep, B., Zheng, Y., 2019)

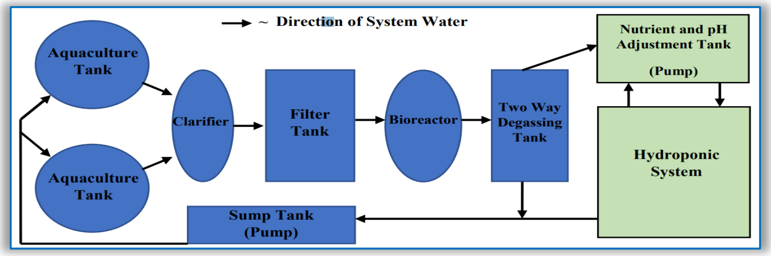

Figure 4 – Example of a decoupled aquaponic system (Yep, B., Zheng, Y., 2019)

Aquaponics is considered an advanced sustainable agricultural method compared to traditional farming systems because it features the concepts of minimal water and nutrient use (*Sanchez, F.A. et al, 2019, Wongkiew, S. et al, 2018*). The use of soilless culture systems such as aquaponics can substantially reduce the potential pollution of water resources with nitrates and phosphates, while contributing to an appreciable reduction in water and fertilizer consumption. Aquaponics uses up to 90% less water than traditional agriculture because water is recycled through the system (*Gruda, N., 2019*). The researchers set up an aquaponic system with coupled recirculation in the plant factory under controlled environmental conditions to produce lettuce on rafts. The aim of the study was to evaluate the yield, mineral status and health–promoting bioactive compounds of Romanian leaf and lettuce cultivars grown in a recirculating aquaponic system. Yield and biometric parameters and quality parameters of lettuce leaves (nitrate, mineral, L–ascorbic acid, carotenoid, phenolic compound and total polyphenol content) were examined. Water monitoring in the aquaponic system showed a low concentration of nitrates, phosphorus (P), potassium (K) and magnesium (Mg), but the proportion of mineral nutrients as well as the pH were stable throughout the lettuce cultivation period. 'Yakina', 'Pivotal' and 'Waygo' romaine lettuce heads averaged 86 g fresh weight, 23% higher than 'Nordice' lettuce over a three–week cultivation period (*Matysiak, B . et al, 2023*).

(a) (b)

Figure 5 – Experimental setup for growing lettuce in a vertical farm (Matysiak, B. et al, 2023)
(a) lettuce grown in hydroponic beds, (b) cork with visible root system of romaine lettuce

For the first time, it has been shown that a recirculating aquaponic system with sturgeon growth can be used to efficiently produce lettuce in a commercial scale plant. Ensuring optimal climatic conditions in the plant factory, including light and temperature, allowed a satisfactory yield and quality of midi romaine lettuce in only 21 days of cultivation. Despite the low mineral content of the aquaponic solution, the mineral content of midi romaine lettuce leaves was in the optimal range, and the nutritional value was similar to that of lettuce traditionally grown in the greenhouse. Biomass production of lettuce and mini romaine lettuce was lower than that of midi romaine lettuce, and leaf nitrate, phosphorus, and potassium contents were below the optimal range. The results indicate that the effectiveness of aquaponics without additional minerals depends on the genotype of the plant, (*Matysiak, B. et al, 2023*).

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

The literature presents a study that is part of a cooperative project to enable the efficient transfer of the innovative ASTAF–PRO aquaponic ecotechnology from Germany to Egypt for aquaculture and sustainable food production. The innovation introduced by ASTAF–PRO is the use of a one–way valve to separate the aquaculture in a classic closed recirculating aquaculture system (RAS) from a classic hydroponic system, thus allowing both systems to operate in optimal conditions. Therefore, a practical experiment was needed to determine which types of aquaponics may be most suitable to help solve the food problem as an alternative to traditional farming methods in Egypt. The ASTAF–PRO unit consisted of three growth tanks (1 m^3 each), a settling tank (1 m^3), bio–filter (1 m^3), three hydroponic washes, two separate pumping units and a valve with a one way (figure 6). in a wooden greenhouse set up for tomatoes. As far as is known, the ASTAF–PRO unit installed in the Faculty of Science, Al–Azhar University, Assiut is the first university unit in Egypt, (*Alaa, G. M. et al, 2021*).

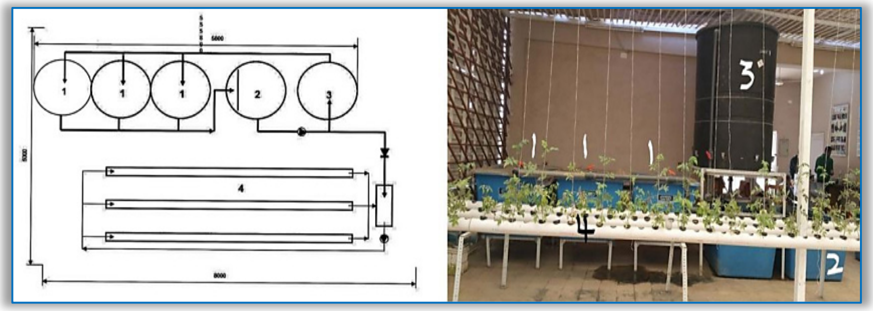

Figure 6 – The design of the ASTAF–PRO basic aquaponics unit that connects RAS and hydroponics through a one–way valve (Alaa, G. M. et al, 2021): 1 growth tanks, 2 sedimentation tanks, 3 biofilters, 4 NFT funds

The results of the water quality parameters from the ASTAF–PRO system showed improvements compared to the water quality from the POND system (a unit that serves as a positive control for conventional commercial aquaculture), especially the level of ammonia, nitrites and nitrates.

The health status of monosex Nile tilapia reared in the ASTAFPRO aquaponic system was better than those reared in the POND system in terms of hematology, biochemistry and immunological status. Obviously, the difference in health status of the fish in the different systems can be related to the water quality, since the same feeds were used. In aquaponics, the nitrite level in ASTAF–PRO was lower than the permissible limit, probably due to the dual action against nitrobacteria present in the biological filters and in the plant growth beds in the system.

3. RESULTS

Georgia researchers compared the life cycles of lettuce and fish farming through 3 separate production strategies:

- lake–based aquaculture and conventional agriculture (BL, CA);
- pond–based aquaculture and conventional agriculture (PB, CA);
- media–based (AP) aquaculture, which uses an expanded clay growing medium instead of soil.

A functional unit of 1 ton (1000 kg) of tilapia and 5 tons of lettuce production from each system was used to compare these methods (*Cohen, A. et al, 2018*).

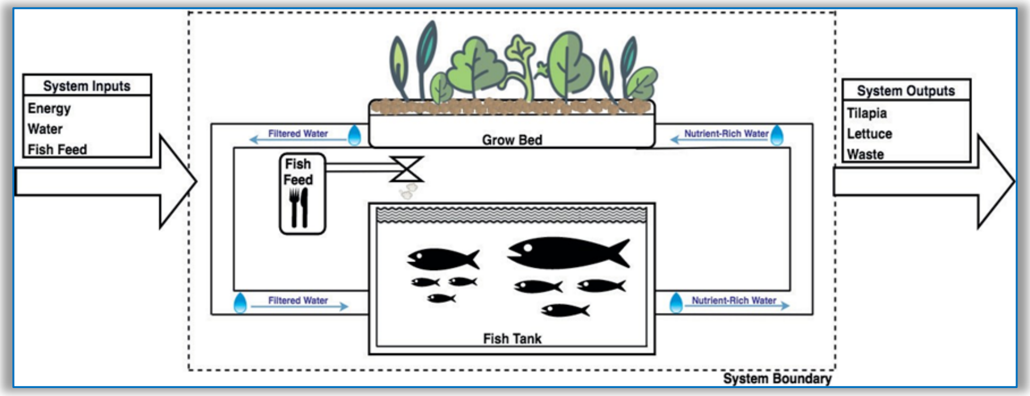

Figure 7 – Scheme of the simplified aquaponic system *(Cohen, A. et al, 2018)*

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The results obtained showed that the use of aquaculture on the health of human health, terrestrial and aquatic ecosystems due to water consumption is reduced by approximately 77% and 97.45%, respectively, compared to the other two methods. An increase in the impact attributed to aquaponic technology was also noted in the categories of mineral resource scarcity and ionizing radiation. These results can also be seen in figure 8.

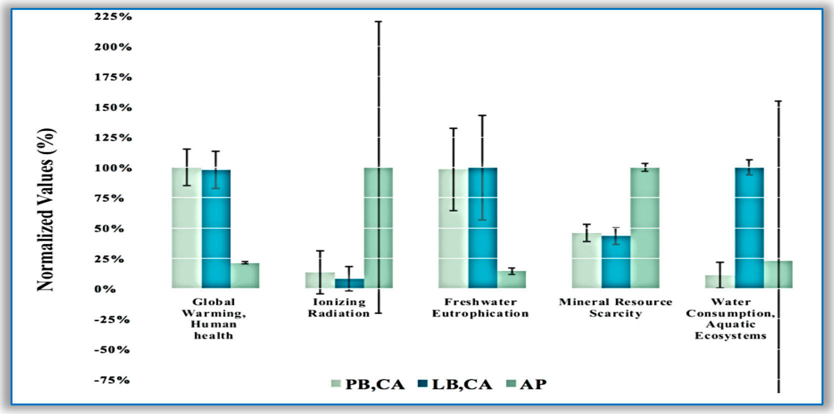

Figure 8 – Selected characterization indicators of lettuce in the 3 strategies *(Cohen, A. et al, 2018)*

A farmer in North America used a 6–500 Clear Flow aquaponic system, built by two contractors, for commercial operations. The aquaponic system has six fish breeding tanks of approximately 1890 L, a biological filtration system, cork plant tanks, filter, media beds and all necessary pumps and hardware. The farmer came complete with plant shelves only. The farm well tapped into a limestone aquifer with a pH of about 7.8. When the fish were introduced into the water, they lowered the pH to about 7.1, which proved to be ideal for growing tilapia. The operation has approximately 11340 L of fish rearing water and a total of approximately 56700 L of recirculated water. After testing the aquaponic system, the farmer concluded that his biggest expense is fish feed, which is still cheaper than plant fertilizer. (*Greenfeld, A., et al, 2021*).

Figure 9 – A 6–500 Clear Flow Aquaponic commercial aquaponic system *(Greenfeld, A., et al, 2021)*

Worldwide, Thorarinsdottir says there are three main aquaponics systems in use: media beds, floating rafts or deep water culture (DWC), and the nutrient film technique (NFT). Media beds use different substrates in an "ebb and flow" process, while in NFT (in a thin layer of water) and raft/DWC (floating rafts in large water tanks) systems, plant roots grow directly into the water as shown in figures 10,11 and 13, (*Thorarinsdottir, R. et al, 2015*).

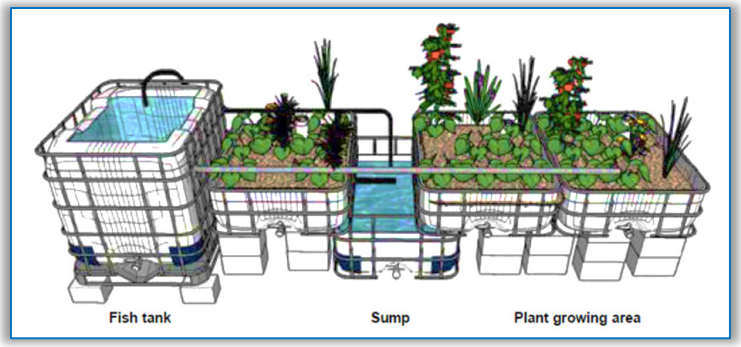

Figure 10 – Small medium bed unit, *(Thorarinsdottir, R. et al, 2015)*

Every coin has two sides. And relying once again on the FAO report, we can also find some weaknesses that come along with adopting an aquaponics design. The weaknesses of aquaponics are:

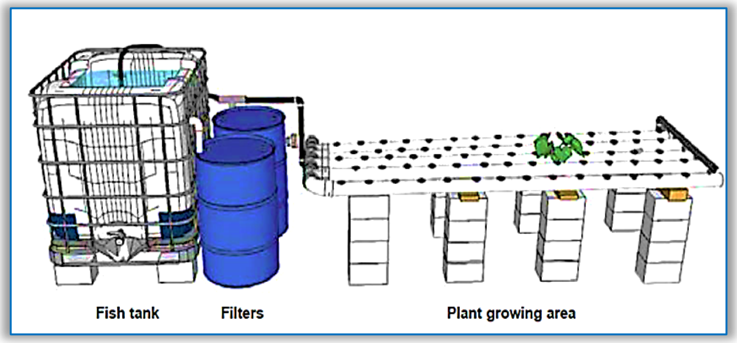

Figure 11 – Small nutrient film technique unit *(Thorarinsdottir, R. et al, 2015)*

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- The very high initial start–up costs (compared to both hydroponics and soil production systems) of aquaponics is one of its weaknesses;
- Aquaponics requires deep expertise in the natural world. To be successful, farmers must have knowledge not only about growing vegetables, but also about how fish and bacteria work. And technical skills in plumbing or wiring are also required;

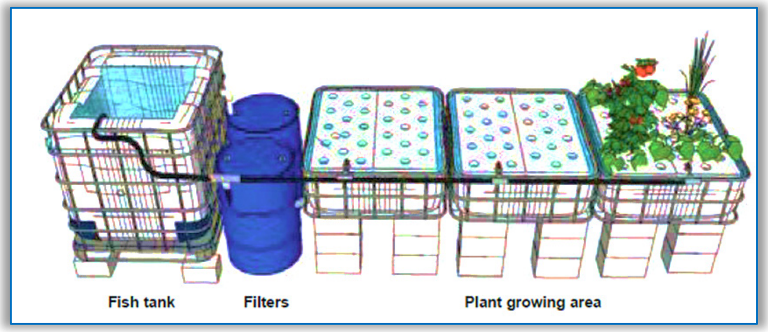

Figure 12 – Small deep water culture unit *(Thorarinsdottir, R. et al, 2015)*

- As a result of the previous point, it is often difficult to find a perfect match between the needs (such as pH, temperature, substrate) of fish and plants;
- Aquaponics has fewer management options (an issue developed in the future) compared to standalone aquaculture or hydroponics;
- System management mistakes can quickly cause its collapse;
- Day–to–day management is required, which means organization is crucial;
- It is energy demand, which means it has energy costs;
- Fish feed must be purchased regularly;
- Aquaponic products alone are not enough to ensure a balanced diet;

Furthermore, an effective aquaponic system must have effective filtration of organic solids – which is the function of bacteria or algae. Over two–thirds of aquaponic system failures occur due to inefficient solid waste disposal. (*FAO, 2014).*

Figure 13 – Aquaponic farm Focsani, Romania *(http://aqua–ponics.ro).*

In Romania, the first aquaculture systems with recirculation were realized at ICDIMPH Horting Bucharest in collaboration with ICDEAPA Galati, SE Aquaterra and Kaviar House, based on a research program that started in 2006 and ended in 2010. The main objective of the project was reducing the level of poverty in disadvantaged areas in Romania, changing the eating habits of the population in those areas towards a diversified diet with beneficial effects on its health (*http://aqua–ponics.ro*).

4. CONCLUSIONS

In conclusion, aquaponics is based on a symbiotic process of growing plants and fish in a recirculating system. The two living components of the system provide each other with the ideal living environment, cleaning each other's water and supporting each other's existence. For this reason, the costs of plant and fish production are considerably reduced.

The classification of aquaponic systems is based on the volume of water used; there are micro systems (with a water volume of a few liters and with a purely decorative role due to the small dimensions; the aquarium has dimensions of 60x60x150 centimeters), small capacity systems (water volume below 3,000 liters, ensures the fish and vegetable consumption of a family), medium capacity systems (with a water volume of up to 10,000 liters, with a production that covers the needs of a family, also allowing small–scale commercialization) and large–capacity systems, ideal for large–scale commercialization of products (water volume of over 10,000 liters, with a production of the order of tons of vegetables and tens of tons of fish).

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Any species of fish can be raised in an aquaponic system. Internationally, Tilapia is preferred, but species such as carp, trout and crucian carp are also suitable. As vegetables and fruits, the easiest to grow in this system are spinach, lettuce, basil, strawberries, okra, mint, parsley, buttercup, stevia and watercress. For the crops of melons, peppers and tomatoes, additions of potassium, calcium and iron are necessary.

Aquaponics appears as a safe alternative in the conditions of climate change – global warming, drought, reduction of water resources. The aquaponic system does not depend on the environment and climate, being located in spaces with controlled temperature and independent of the soil. It also falls into the series of advantages and the following:

- two productions (vegetables and fish) are obtained with a single input (fish food);
- vegetable production is four to eight times higher than in the case of classic crops (in the field), due to the planting density, higher than on the ground, and the permanent supply of water and nutrients;
- the products do not contain substances chemical;
- in protected spaces, vegetable production is obtained regardless of the season;
- vegetables can also be grown on vertical, reducing the land surface used.

There are only two disadvantages of aquaponics:

- the costs related to energy consumption in the cold period of the year, the consumption being similar to that of heated greenhouses, and
- the risks involved in the accidental shutdown of the electric current for long periods of time;

In this case, water recirculation in the system stops and the purification process is affected, leading to an increase in the concentration of toxic substances in the pools. To eliminate this risk, install a power generator that automatically starts up in the event of a breakdown. There is also the alternative of solar panels.

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References

[1] Alaa, G. M. et al, (2021). Water quality and health status of the monosex Nile Tilapia, Oreochromis niloticus cultured in aquaponics system (ASTAF–PRO), Egyptian Journal of Aquatic Biology & Fisheries, Vol. 25(2): 785– 802.

[2] Cohen, A. et al, (2018). Combined Fish and Lettuce Cultivation: An Aquaponics Life Cycle Assessment. Procedia CIRP, 69(), 551–556.

[3] David, C. et al, (2021). Aquaponics: Current state and prospectives, Farming connect.

[4] Greenfeld, A., et al, (2021). Monetizing environmental impact of integrated aquaponic farming compared to separate systems. Science of The Total Environment, 792, 148459.

[5] Goddek, S. (2015). Challenges of Sustainable and Commercial Aquaponics. Sustainability, 7, 4199–4224

[6] Gruda N. (2019). Increasing Sustainability of Growing Media Constituents and Stand–Alone Substrates in Soilless Culture Systems. Agronomy, 9, 298.

[7] Kloas W. et al, (2015). A new concept for aquaponic systems to improve sustainability, increase productivity, and reduce environmental impacts. Aquac Environ Interact. **7**(2): 179–192.

[8] Körner O., (2021). Environmental impact assessment of local decoupled multi–loop aquaponics in an urban context. J. Clean. Prod., 313, 127735.

[9] Matysiak, B.; et al.,(2023). Growth and Quality of Leaf and Romaine Lettuce Grown on a Vertical Farm in an Aquaponics System: Results of Farm Research. Agriculture, 13, 897.

[10] McMurtry M.R. et al, (1997). Efficiency of water use of an integrated fish/vegetable co–culture system. J World Aquacult Soc. ;28(4):420–428).

[11] Naegel L.C.A., (1977).Combined production of fish and plants in recirculating water. Aquaculture.;10(1):17–24; .

[12] Rennert B. et al, (1989). The possibility of combined fish and vegetable production in greenhouses. Adv Fish Sci. 8:19–27;

[13] Sanchez F.A et al.(2019). Tilapia recirculating aquaculture systems as a source of plant growth promoting bacteria. Aquac. Res., 50, 2054–2065.

[14] Sneed K., (1975). Fish farming and hydroponics. Aquac Fish Farm. 2(1):18–20.

[15] Thorarinsdottir, R. et al, (2015). Aquaponics Guidelines, University of Iceland.

[16] Tyson,R.V. et al.,(2018). Opportunities and Challenges to Sustainability in Aquaponic Systems. HortTechnology, 21, 6–13.

[17] Wongkiew, S. et al.(2018). Aquaponic systems for sustainable resource recovery: Linking nitrogen transformations to microbial communities. Environ. Sci. Technol. 52, 12728–12739.

[18] Yanes, A. R. et al.(2020). Towards automated aquaponics: A review on monitoring, IoT, and smart systems. Journal of Cleaner Production, 121571

[19] Yep, B., Zheng, Y., (2019). Aquaponic trends and challenges e a review. J. Clean. Prod., 228.

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