Journal of Young Scientist, Volume X, 2023
ISSN 2344 - 1283; ISSN CD-ROM 2344 - 1291; ISSN Online 2344 - 1305; ISSN-L 2344 – 1283

REVIEW ON AQUAPONIC SYSTEMS AND THEIR POTENTIAL IN THE REALM OF SUSTAINABLE AGRICULTURAL PRACTICES

Andra-Ioana BALAUR[1]

Scientific Coordinator: Lect. PhD Eng. Alexandru Ioan CĂLIN[2]

[1]Politehnica University of Bucharest, 313 Spl. Independentei, District 6, 011464, Bucharest, Romania, Phone: +40 21 402 96, Email: andra.ioana.balaur@gmail.com
[2]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Mărăşti Blvd, District 1, 011464, Bucharest, Romania, Phone: +4021.318.25.64, Fax: + 4021.318.25.67, Email: alexcalin@fifim.ro

Corresponding author email: andra.ioana.balaur@gmail.com

Abstract

This article is an overview of the agricultural practice by the name of "aquaponics", which merges aquaculture and hydroponics (growing vegetables in a soilless environment) in a completely controlled environment in order to ensure sustainable food production, thus eliminating the obstacles induced by meteorological conditions, scarce resources, lack of farmland, and other external factors threatening large-scale food security. This paper will present the working principle of this relatively new farming practice and provide a look at the advantages and disadvantages of using aquatics for agricultural production. With a better understanding of this technology and its true potential, all the while taking into account the minimisation of any associated environmental impact, it has been found that aquaponic systems constitute one of the ways of the future in terms of sustainable farming practices.

Key words: *aquaculture, aquaponics, hydroponics, sustainability.*

INTRODUCTION

Aquaponics is an agricultural practice that combines aquaculture (fish farming) and hydroponics (growing plants without soil). It is a form of sustainable agriculture that uses a closed-loop water recirculation system (Figure 1) to produce food from a combination of fish, vegetables, and micro-organisms [1]. In recent years, it has gained ground as a viable alternative to traditional agriculture because of its potential to reduce environmental impact while ensuring food security [2]. Aquaponics systems can produce both fish and vegetables without the need for large areas of land or large inputs of water, fertilisers, and pesticides. This makes them ideal for urban environments where space is limited, and resources are scarce.

Aquaponic systems have many advantages over conventional farming methods, such as reduced water use, increased efficiency in nutrient cycling, reduced use of hazardous chemicals, improved soil quality and preservation of biodiversity. In addition, they can be used to produce higher yields with less effort than other types of agriculture, as they require fewer labour hours per unit area compared to traditional farming practices [3].

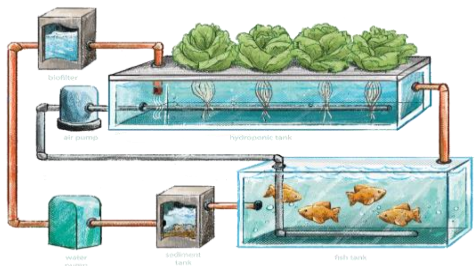

Figure 1. Diagram of an Aquaponic System

However, despite these benefits, there are still some challenges associated with this technology that need to be addressed if it is to be widely adopted by farmers around the world.

MATERIALS AND METHODS

An aquaponic system combines aquaculture and hydroponics thus creating an efficient form of food production. Aquaculture is a type of farming that involves raising fish and other aquatic animals in ponds or enclosed plants without soil, instead using various nutrient solutions that the plants require. Those nutrients are absorbed by the plant roots, which are submerged in water. The plants grow on floating rafts or other physical support systems that also ideally deprive the water of sunlight to prevent algae from forming therein.

Aquaponics therefore involves using aquatic animals such as fish, shrimp, crayfish, or frogs together with plants grown in water without soil. This symbiotic relationship between the two elements allows for an efficient nutrient cycle that can take place without the use of chemical fertilizers or pesticides [4].

The fish are housed in a special aquarium called a grow-out aquarium, where they produce waste that is then converted by nitrifying bacteria into nutrients that can be used by plants growing in a connected hydroponic system. Water from the fish tank is then circulated through the hydroponic system and filtered before returning to the tank. This process provides an organic source of nutrients for the plants and at the same time cleans the water for the aquatic life that lives in the grow-out tanks.

Nutrient cycling is an essential part of the aquaponic system as it allows efficient use of resources such as fish waste and nutrients for plant growth. Nutrients in an aquaponic system are circulated in a two-step process. The bacteria involved in this process are mainly composed of two types: nitrifying bacteria and denitrifying bacteria.

The first step is the conversion of fish waste by bacteria into nitrates, which are then used as nutrients for plants grown in the same medium (water). Nitrifying bacteria, such as Nitrosomonas and Nitrospira, convert ammonia from fish waste into nitrites and then eventually into nitrates that are easily absorbed by plants. These types of bacteria need oxygen to carry out their metabolic processes, making them strictly aerobic (oxygen-dependent) organisms.

The second stage involves denitrification, in which denitrifying bacteria convert nitrates back into nitrogen gas or other forms that can be released into the atmosphere. Denitrifying bacteria, the Paracoccus species being a prime example, are strictly anaerobic (oxygen-independent) organisms that rely on alternative energy sources, rather than oxygen, to convert nutrients back into forms useful for plant growth, as well as to transport them away from the root zone when concentrations become too high [4].

The water that has been filtered by these bacteria re-enters the fish tank and thus, a nutrient cycle is completed. The aquarium usually has a conical base, allowing the fish waste to settle and to be easily discharged at certain intervals.

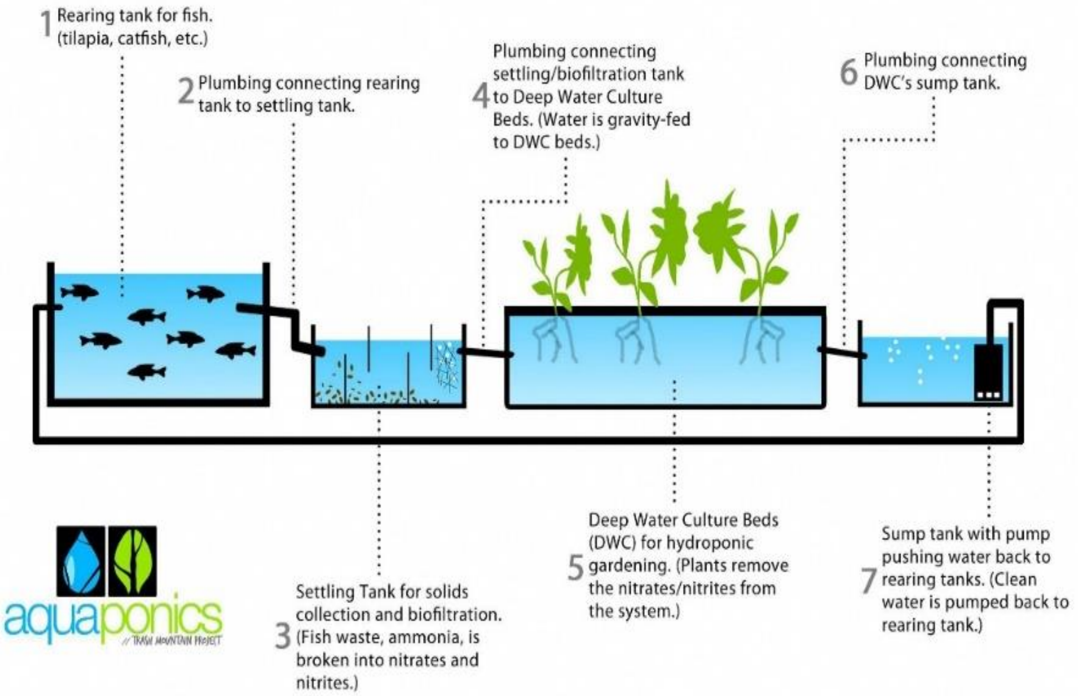

Figure 2. Deep Water Culture Aquaponic System, working principle

For this process to function properly, several key parameters need to be closely monitored and properly managed. These include, among others, pH levels, oxygenation levels, temperature, and stocking density. The ideal pH range for aquaponics is between 6-7 [5], which helps to ensure optimal growing conditions for both fish and plants. In addition, oxygenation levels should also remain within specific ranges, depending on the species grown in each individual system, as this will allow them to thrive while providing enough oxygen to support plant growth. The temperature should also remain consistently warm enough, but not too warm, as this could lead to serious health problems for both aquatic life and plants. The temperature intervals vary depending on the species of aquatic life and plants that have been chosen in a specific aquaponic system.

Aquatic stocking density is another key factor to consider when setting up an aquatic system, as overcrowding can lead to competition between fish, further leading to decreased fish growth rates, and poor water quality due to increased waste from overcrowding. Low-quality water can cause stress (toxicity) on both biological systems, which can lead to poor performance or even death if not managed correctly [6]. It is therefore important to strictly maintain the number of fish required for optimal production, while ensuring that dissolved oxygen levels in the water remain sufficiently high throughout the process cycle so as not to compromise the ability of both organism types to perform their respective roles effectively in their respective environments.

There are several types of plant growing beds:

- Deep Water Culture Beds

Deep Water Culture beds (Figure 3) are flat-bottomed channel-containers, with water that runs 30cm deep, covered with floating rafts made of styrofoam or similar materials. The plants are supported by a cubic structure made of coconut coir or a similar material, which is then placed in same-size holes drilled in the floating rafts. Therefore, the roots of the plants are immersed in water, while the rest of the plant sits on top of the raft, having access to sunlight and proper aeration. The raft itself provides stability for the plants, reducing the risk of tipping or falling over, and the water film allows efficient water flow, ensuring that the plants receive the nutrients and oxygen they need [7].

Figure 3. Floating rafts on a Deep Water Culture system

Leafy greens such as lettuce, cabbage, and spinach, as well as herbs such as basil and parsley, are ideal crops for the DWC system.

- Grow Media Beds

These are culture beds containing a culture medium (Figure 4 and Figure 5), such as clay or coconut pebbles, which represent the biological filtering surface (conversion of ammonia to nitrate) of the water by the bacteria. Water from the aquarium is pumped into the growth medium, and the plants absorb nutrients as the water filters through the growth medium. This type of grow bed gives better control over the growth medium, as the growth medium can be adjusted to give the plants optimal conditions. In addition, media beds offer the ability to adjust water flow, pH and nutrient levels [7].

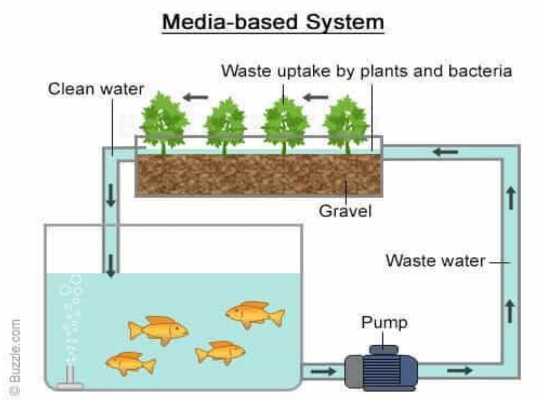

Figure 4. Grow Media Aquaponic System, working principle

A wide variety of crops can be grown in growing medium beds, including tomatoes, peppers, cucumbers, zucchini and root vegetables such as carrots and beets.

Figure 5. Grow media small scale aquaponic system

- Nutritional Film Technique (NFT)

Nutrient film technique (NFT) channels are narrow channels through which a thin film of water constantly flows, supplying nutrients to plant roots. The plants are suspended above the water and their roots are in direct contact with the water. NFT canals (Figure 6) are very efficient because the flow of water is carefully and more easily controlled than in DWC systems (Figure 7) to ensure that plants receive the exact amount of nutrients and oxygen they need [7].

Figure 6. Nutrient Film Technique commercial aquaponic system

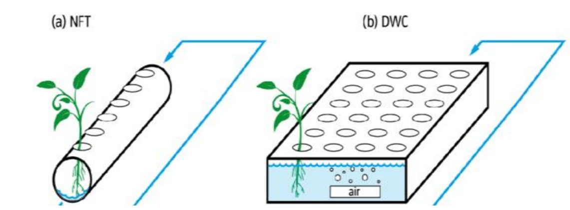

Figure 7. Comparison between NFT and DWC channels regarding water flow

NFT channels are best suited for small, fast-growing crops that don't need much support, such as strawberries, lettuce, herbs, and microgreens.

- Vertical Grow Beds

Vertical culture beds (Figure 8) are large tubes with holes designed to grow plants vertically, either by layering layers of culture beds or by using a porous material attached to the inside of the walls [7]. They are often used in compact aquaponic setups because they allow more plants to be grown in a smaller space. Vertical orientation also gives plants better access to light, which is essential for optimal growth.

Figure 8. Vertical Grow Beds

Spinach, herbs and small fruit crops such as strawberries are ideal crops for vertical growing beds because they do not require much space for roots.

RESULTS AND DISCUSSIONS

Regarding the aquaculture part of the system, it has been found, through trial and error, that certain types of fish offer specific advantages over others and should be selected accordingly.
For commercial aquaculture systems, tilapia is considered the best choice due to its fast growth rate, high tolerance to overcrowding conditions and large size, making them ideal for harvesting. Other popular species include barramundi, perch, catfish and carp. All of these species are hardy fish that can tolerate a wide range of pH levels, making them ideal for aquatic systems as they allow greater control over water chemistry, which helps promote healthy plant growth.
However, for recreational smaller systems (hobby-scale), more exotic species such as koi and goldfish are sometimes preferred as they offer more colour options to choose from. In addition, these smaller ornamental species tend

to produce less waste than larger commercial-sized species, allowing users with smaller systems to maintain reasonable stocking levels without having to worry about excessive nutrient levels or water quality, minimizing the stringency of monitoring required.
When selecting any type of fish for an aquaponic system, it is important to remember that all types have their own individual needs, so it is important to research each species in detail before introducing them into your system so as not to cause suffering to the living or water quality problems that could lead to poor health or death among plants and fish [8].
In addition, it is also important to note that the more sensitive cold-water fish species should only be kept in regions where temperature fluctuations remain constant throughout the year, as otherwise they are at risk of disease due to sudden changes in temperature, with climate thus playing an important role in fish choice.
Regarding the plant-growing part of the system, the most common type of plants grown in aquaponic systems are robust leafy plants such as lettuce, spinach, Brussels sprouts, rocket, garden cabbage and red beetroot. These crops grow well in the conditions provided by an aquaponic environment and can withstand temperature fluctuations. Other vegetables that do well in aquaponics include broccoli, cauliflower, cabbage, celery, peppers and tomatoes. Herbs such as basil and dill also have a high output in this type of system.
Fruit crops such as strawberries can be grown in an aquaponic system, as long as they are planted with the understanding that there will be a longer harvest time due to the cooler temperatures typically found in these systems compared to outdoor production facilities. Other fruits such as blueberries, grapes and pomegranates can also be grown, but need additional support structures such as trellises or grids to provide support for their delicate branches.
Root crops, such as potatoes and carrots, can also be grown successfully in an aquaponic system, although they require higher amounts of nutrients than other types of plants because of their higher metabolic requirements. The same is true for legumes such as peas or beans, which often require additional support structures such as trellises or arches to ensure adequate structural integrity.
In addition to vegetables and fruit, ornamental plants such as water lilies and mosses can be grown, which not only provide aesthetic benefits, but can help filter impurities from the water in the system and at the same time increase oxygenation levels. Many people even grow edible flowers, such as chickpeas, which provide both beauty and flavor when used as a garnish on salads or other dishes [9].
In general, it is important to note that not all types of plants will grow equally well in an aquaponic system, so conducting a detailed survey of each species prior to planting is recommended for maximized success rates along with improved yields over traditional farming methods. In addition, investing in appropriate support structures when necessary should help ensure healthier crop growth while limiting potential losses due to unfavorable environmental conditions for plant development.

- Advantages of aquaponic systems

Compared to traditional agriculture, aquaponic systems require far fewer resources for the same production yield and have many benefits which will be detailed below.
For a start, aquaponics offers great versatility due to the controlled environment in which it is carried out. Unlike traditional farming methods, aquaponics systems allow complete control over humidity and heat levels in the greenhouse, ensuring optimal growing conditions for plants and fish throughout the year. This means that vegetable production can take place in any climate or region - making it a viable option for those living in areas with extreme or highly changeable weather patterns, where outdoor growing is not possible or is severely limited by the seasons.
Also because of the controlled environment in which it sits, the aquaponic system is also less prone to pests and other common agricultural threats because there are no outdoor soil beds or other exposed areas for insects or animals to enter. By creating a water-based system instead, only bacteria and micro-organisms used as part of the natural nitrogen cycle will be present - helping to reduce the risk of contamination from

outside sources, while reducing the need for costly chemical fertilizers and pesticides.
In addition, by eliminating the need for tillage, aquaponic systems take up much less space than conventional cultivation methods, while still producing high yields per unit area due to the faster growth rate associated with this type of cultivation. With careful planning and design, multiple aquaria and culture beds can even be linked together into larger networks capable of producing enough food for entire communities - something that would otherwise be impossible with traditional farming techniques.
Given the fact that the aquaponic system is a closed circuit and recirculating, water can be reused several times without the need for frequent replacements or refills. In addition, due to the absence of soil in an aquaponic system, less water is lost that would have been lost through soil absorption and evaporation, saving up to 90% of total water consumption compared to traditional cultivation methods [11]. In addition, since there is no need for soil loosening, compaction due to machine traffic is drastically reduced, leading to higher levels of bioactivity in the root zone, which helps reduce nutrient leaching into nearby water bodies and other areas where it could be harmful due to excessive concentrations accumulating over time [10].
In parallel to water savings, aquaponics also allows significant energy savings compared to traditional agriculture. Due to its small size and increased efficiency, aquaponics systems require much less energy than traditional farming techniques, leading to energy savings of between 10 and 20%, according to The International Journal of Agricultural Research (IJAR) [12]. These savings come from various factors, such as reducing the need for chemical fertilization, pest control treatments and irrigation equipment, all of which consume large amounts of electricity and fuel when used in conventional farming practices.
Finally, aquaponics systems reduce reliance on expensive chemical fertilizers, which not only reduces the costs associated with production, but also eliminates most of the environmental impacts associated with typical farming practices, such as synthetic runoff and over-fertilization. Fish waste provides a high level of readily available nitrogen, phosphorus and other essential minerals that can be taken up directly by plants growing in an aquaponic system, rather than having to be pre-processed with fertilizer before application. This not only provides a sustainable source of nutrients for plant growth, but also makes it easier for farmers using this method, as they don't have to worry about purchasing additional chemicals or treatments needed for their crops to thrive. In turn, this increases the quality of production, resulting in fruit and vegetables with far less harmful effects on the human body compared to produce from pesticide-dependent crops.

- Disadvantages of aquaponic systems

Despite their many benefits, there are also some risks associated with aquaponic systems when implemented widely or in certain environments. For example, if not managed properly, these systems can create an increased demand for energy sources such as electricity or fuel, which could have a negative impact on could disrupt natural habitats and species diversity if not handled responsibly [13].
Also, in terms of waste resulting from the production process in an aquaponic system, this includes solid organic waste from fish, wastewater that needs to be replaced after a certain number of circulation cycles in the system, plastic plates in which plants grow that need to be replaced due to potential damage, and consumable parts of water filters and oxygen pumps, and water pumps. Of course, if organic waste is composted, wastewater is transferred to a treatment plant, and recyclable materials are recycled and reclaimed, the aquaponic system is much more environmentally friendly than traditional farming practices, which affect the environment in a much more direct way, polluting both soil, air and waterways through the pesticides and synthetics used and the greenhouse gas emissions from large agricultural machinery, for example.
Although it has no direct environmental impact, one of the biggest drawbacks of an aquaponic system is the time, effort and money required to set it up. Unlike traditional farming methods, where land can easily be purchased and sowing seeds is enough to start growing crops, setting up an aquaponic system requires careful planning and detailed analysis to ensure its long-term success. Firstly, the appropriate components for the functional loop must be

selected and purchased. This usually includes items such as an aquarium, plant culture bed, filtration unit, air pump, water heater, hydroponic nutrients (for nutrient supplementation, if applicable), fish feed and other necessary supplies, making this form of food production an expensive affair. Secondly, once all the components have been purchased, they must then be properly installed to ensure optimal performance. Depending on the complexity of the system, this may require a significant amount of knowledge in plumbing and electrical installation techniques [13].

Finally, an equally important step and potential hurdle is the monitoring and maintenance of the aquaponic system. This includes regular testing of pH levels as well as nutrient concentrations in the water - both of which must remain within accepted ranges for optimal growing conditions for both plants and fish. In addition, any mechanical or electrical component needs regular overhauls or repairs in case something breaks down due to wear and tear from constant use [14]. Thus, setting up an aquaponic system involves a significant amount of time, effort, and resources. However, with careful planning combined with a little determination, anyone can succeed in growing their own fresh produce.

CONCLUSIONS

Aquaponics is a sustainable and beneficial farming practice that offers numerous advantages over traditional farming practices. It uses up to 90% less water while producing high quality crops. It has the potential to produce enough food for entire communities due to its versatility in any climate or region and eliminates the need to till the land, which reduces the environmental impact associated with conventional farming methods. Also, with careful management and monitoring, there is little risk of spreading disease or pests among fish and plants - making it one of the safest ways to grow produce. By eliminating the use of pesticides, agricultural production is healthy, organic and has no harmful effects on the human body.

Although traditional agriculture still plays an important role in feeding our population today, it cannot compete with aquaponics when it comes to resource conservation and sustainability. By taking advantage of natural processes such as microbial activity and nutrient cycling in a closed-loop design system, aquaponic systems offer significant reductions in both operational costs and environmental impact, while providing equivalent or even higher production yields than traditional farming techniques.

Despite a few drawbacks, aquaponics systems are a viable alternative to traditional agriculture, given their greater efficiency when properly managed and maintained.

It should be noted that it is a technique in continuous development, with future optimisation and automation potentially making it the most cost-effective method of agricultural production available to mankind.

In conclusion, aquaponics is a state-of-the-art new technology that offers an efficient and sustainable alternative to traditional agriculture. It is, in short, the way of the future in terms of sustainable farming practices.

REFERENCES

[1].https://www.permaculturenews.org/2016/05/30/what-is-aquaponics-and-how-does-it-work/, lastly visited on 10th of April 2023

[2].https://cropforlife.com/aquaponics-is-gaining-popularity-as-more-people-grow-plants-using-fish-poop/, lastly visited on 10th of April 2023

[3].https://derwent.es/en/aquaponics-advantages/#:~:text=Aquaponics%20Advantages,of%20oceans%20or%20soil%20degradation., lastly visited on 10th of April 2023

[4].https://www.acvaponie.ro/acvaponie.html, lastly visited on 10th of April 2023

[5].https://sensorex.com/2017/10/20/aquaponics-water-quality/, lastly visited on 10th of April 2023

[6].https://aquaponics.africa/2021/10/06/stocking-density-in-aquaponics, lastly visited on 10th of April 2023

[7].https://seretransilvania.ro/ro/blog/post/ce-este-acvaponia, lastly visited on 10th of April 2023

[8].https://www.howtoaquaponic.com/fish/best-fish-for-aquaponics/, lastly visited on 10th of April 2023

[9].https://www.howtoaquaponic.com/plants/best-plants-for-aquaponics/, lastly visited on 10th of April 2023

[10].https://farmingmethod.com/aquaponics-description-advantages-disadvantages/, lastly visited on 10th of April 2023

[11].https://farmingaquaponics.com/do-aquaponics-systems-save-water/#:~:text=Yes%2C%20studies%20have%20shown%20that%20aquaponics%20uses%2090%25,from%20the%20fish%20tanks%20to%20the%20plant%20beds., lastly visited on 14th of April 2023

[12].https://www.sciencedirect.com/science/article/abs/pii/S2212609019301567?via%3Dihub , lastly visited on 14th of April 2023
[13].https://gardential.com/disadvantages-of-aquaponics#:~:text=Aquaponics%20supports%20the%20symbiotic%20relationship%20between%20plants%20and,and%20the%20expensive%20cost%20for%20the%20system%20set-up., lastly visited on 14th of April 2023
[14].https://thehydroponicsplanet.com/5-disadvantages-of-aquaponics/, lastly visited on 14th of April 2023

References of illustrative materials

https://earth.org/wp/content/uploads/2020/08/Aquaponics1.png, lastly visited on 14th of April 2023
https://i.pinimg.com/originals/fa/a0/e4/faa0e46cfc80334ad2d3c6dafbc4a380.jpg, lastly visited on 14th of April 2023
https://cdn.shopify.com/s/files/1/2307/4917/files/5_600x600.jpg?v=1651630498, lastly visited on 14th of April 2023
https://organicgardentips.com/wp-content/uploads/2020/04/aquaponics-media-based.jpg, lastly visited on 14th of April 2023
https://learn.eartheasy.com/site-files/2019/02/aquaponics03.jpg, lastly visited on 14th of April 2023
https://www.dahuiaquaculture.com/wp-content/uploads/2021/05/WeChat-Image_20210407130633.jpg, lastly visited on 14th of April 2023
https://www.researchgate.net/publication/320619425/figure/fig3/AS:553536535699456@1508984802245/Illustration-of-a-nutrient-flow-technique-NFT-and-b-deep-water-culture-DWC.png, lastly visited on 14th of April 2023
https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcQpunVJTe-bhxPSsNLyqAtcdBC3g0of5f7hQj3B-9idf2zjwUUicHuyRrGo1nu7HnXcDDc&usqp=CAU, lastly visited on 14th of April 2023