AQUAPONICS AND PATHOGENIC CONTROL

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Abstract:

Hunger is considered a global issue and tends to increase with each passing day. The climate crisis, frequently occurring catastrophic natural events, and overpopulation have dramatically increased food insecurity worldwide. We happen to have only a limited arable land resource to grow more food. Likewise, several agricultural practices are unsustainable, leading to environmental pollution and degradation. Aquaponics provides a sustainable means of producing crops without the utilization of soil. Aquaponics is a combination of hydroponics and aquaculture, offering dual benefits of cultivating plants and rearing fish. Aquaponics is not a sterile system and houses several microbial florae, which are beneficial in the process of nitrification and nutrient cycling. However, the aquaponics system much like any other agricultural system is prone to pathogenic attack. The pathogens cause a wide array of diseases in plants and fish, which ultimately impacts the productivity of the system. Several biological control measures have been developed and implemented to safeguard the aquaponic system. The optimization of each functional parameter in the system leads to a successful cultivable soilless system.

Keywords:

Aquaponics, Flood and Drain technique, Nutrient Film technique, Pathogenic control, Biological Control Agents.

1 Introduction

The climate crisis is not a novel phenomenon anymore, but a global issue. Several nations of the world are combating the adverse impacts of climate change and extreme temperatures by spending a very large portion of their economy. The Climate crisis has pushed the global population to a point with no return. Several cataphoric events frequently witnessed on the earth such as droughts, floods, famines are only a superficial image of the issues lying deep within. The droughts and floods have impacted the socio-economic framework of society by accelerating water and food insecurities. With each passing day, the struggle of getting clean water and two meals a day is exponentially increasing. Around 6% of the world's population didn't have access to improved water resources in 2020 (Ritchie & Roser, 2021). Likewise, between 720 and 811 million people worldwide faced hunger as of 2020 (FAO, 2021). Growing more food holds an imperative position for eliminating the hunger crisis globally. However, the arable lands are limited and most of them have already been cultivated.

The only solution to this dire situation rests in implementation of **vertical farming** techniques such as hydroponics, aeroponics, and aquaponics. These methods involve the soil-less cultivation of plants indoors, in vertically stacked layers, in well-regulated and optimized environmental conditions. Such systems not only improve the productivity of the plants but utilize less space as compared to traditional farming. Moreover, these systems remain productive throughout the year, are unaffected by the environmental stresses, require less water, recycle the water, eliminate the use of chemical fertilizers, and are highly energy-efficient systems with low labor costs. Several vertical farms in an urban setting support the quick and fresh delivery of the produce in the nearby places, reducing the cost of transportation and utilization of fossil fuels, thereby controlling the pollution.

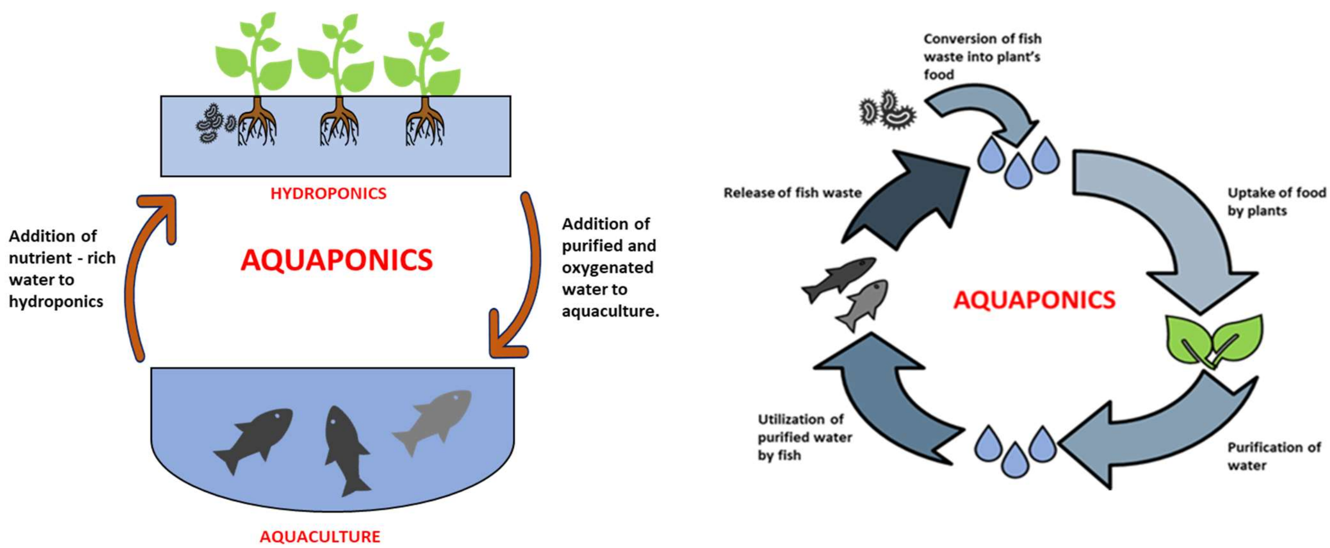
The paper discusses one of the techniques of vertical farming techniques – Aquaponics. Aquaponics is a simple, promising, and sustainable food production technology in which there is an integration of hydroponics and aquaculture in a recirculating manner. The system provides a dual advantage of growing food and culturing fish.

2 What is Aquaponics?

Aquaponics incorporates a symbiotic combination of two systems: (a) Hydroponics – growing plants (without soil) in water and (b) Aquaculture - rearing fish. The water essentially re-cycles within these two systems. The plants consume the waste released by the fish resulting in the purification and oxygenation of water by plants for supporting the growth of fish in the system. The naturally occurring bacteria/bacteria present on the plant's root convert the fish waste (ammonia) present in water to nitrate (plant's nutrient) by the process of nitrification. The subsequent absorption of nitrates by the plants enhances their growth.

The three essential components of the system, i.e., fish, plants, and bacteria live side-by-side and function together for the creation of a mutually advantageous environment. Therefore, a successful, healthy, and functional system necessitates the correct balance between the three components. Achieving this balance requires optimization and thorough knowledge of each component of the system. It involves several trials and errors as well as technical know-how to develop a successful aquaponic system.

A schematic diagram of an aquaponic system is illustrated in Figure 1 (a, b).



a *b*

Figure 1 (a, b) Aquaponics - Process Overview

The plants have a few fundamental needs for growing successfully, which include air, water, sunlight, and nutrients. These essentials along with the process of photosynthesis enable the plants to form their food in form of glucose, which constitutes the building block of all the vegetative matter. In an aquaponic system, fish serve as the provider of nutrients to the plants in contrast to the manures used in conventional farming techniques. The bacteria present in the system process the fish waste because the accumulation of fish waste at high levels proves to be toxic to the fish, converting into a highly accessible form by the plants.

The aquaponic cycle begins with the feeding of fish. The waste matter generated by the fish gets converted into nitrates by the nitrifying bacteria, which in turn is utilized by plants for their growth. The plant filters the water and returns the water to the fish tank.

3 Ideal growing conditions

The optimization and regulation of growing conditions in aquaponics are far more complicated than conventional farming techniques. A successful aquaponic system must attain all the ideal conditions. A few of the ideal growing parameters are as listed:

3.1 Sunlight

The plants growing in the aquaponic system have normal sunlight requirements, i.e., between 2 to 6 hours, depending upon the variety. However, the fish, bacteria, and exposed water in the aquaponic system require protection from direct sunlight. Therefore, while the sunlight forms a vital requirement for robust plant growth, the rest of the system requires to be shaded. However, if the setting doesn't permit the use of sunlight for the system, artificial light can be used for a similar purpose. However, similar precautions must be taken for protecting fish and bacteria as with sunlight. The system should likewise, prevent the growth of algae in the exposed water.

3.2 Temperature

Ambient temperatures should be considered before designing the aquaponic system. However, the temperature of the water is the vital parameter to be optimized for the successful functionality of the system. The plants generally grow over a wide spectrum of temperatures; however, the temperature range is quite small for fish and bacteria. Fish display high susceptibility towards temperature fluctuations and thereby, the water should be shaded to maintain the water temperature with regular water temperature monitoring. Similarly, the nitrifying bacteria supports maximum nitrification at the temperature between 15˚C – 30˚C (Walsworth, 2016), therefore, the system requires efficient protection from low temperatures. The temperature below the freezing not only impacts the biotic components of the system but also deteriorates the pumping and piping network of the system.

3.3 Protection from other abiotic components

Although sunlight and temperature are the essentials for building aquaponic systems, they should be safeguarded from the under listed parameters:

- Wind: It impacts the water temperature and the rate of evaporation, thereby, the system requires some protection from direct breeze.
- Rainfall: It alters the pH and nutrient contents of system which fails the system. Thus, the system must be protected from rain by constructing a cover over it.

3.4 Space

The aquaponic system can be extensively compact if required and can be modified into any size. The first-time growers may begin with a very small system which could be later expanded once the several factors are optimized.

3.5 Location

The selection of appropriate locations forms the basis of the success of aquaponics. An ideal location must be considered all the above-mentioned parameters. However, the system should be daily monitored for all its parameters, therefore, it should be easily visible from the grower's house. The location should likewise have constant electricity and water supply. The system should be secured from pets and animals.

4 Types of Aquaponic Systems

The selection of the aquaponics design largely depends upon the abiotic condition of the region as well as the on the ease of achieving a balance between the bacteria, fish, and plants. Irrespective of the type of the system, each aquaponic system comprises the following components:

- A grow bed (substrate) for growing plants.
- A fish tank for culturing of fish.
- A pump to transfer the water from the fish tank to the grow bed and helps in recirculating the water.
- Siphons that drain the water from the grow bed to the fish tank (in the case of the Flood and Drain system)

The commonly used systems are as illustrated under:

4.1 Flood and Drain Technique:

The flood and Drain technique involves the flooding of the grow bed to irrigate the plants, followed by draining of water back to the fish tank. This technique utilizes a bell siphon to regulate the water level in the system. The system comprises the fish tank and grow bed to support the growth of fish and plants respectively. The grow bed, likewise serves as a mechanical and biological filter for the purification of water. The grow bed encompasses LECA (Lightweight expanded clay aggregate, which promotes the growth of nitrifying bacteria and anchors the plants.

The system overview is illustrated in figure 2.

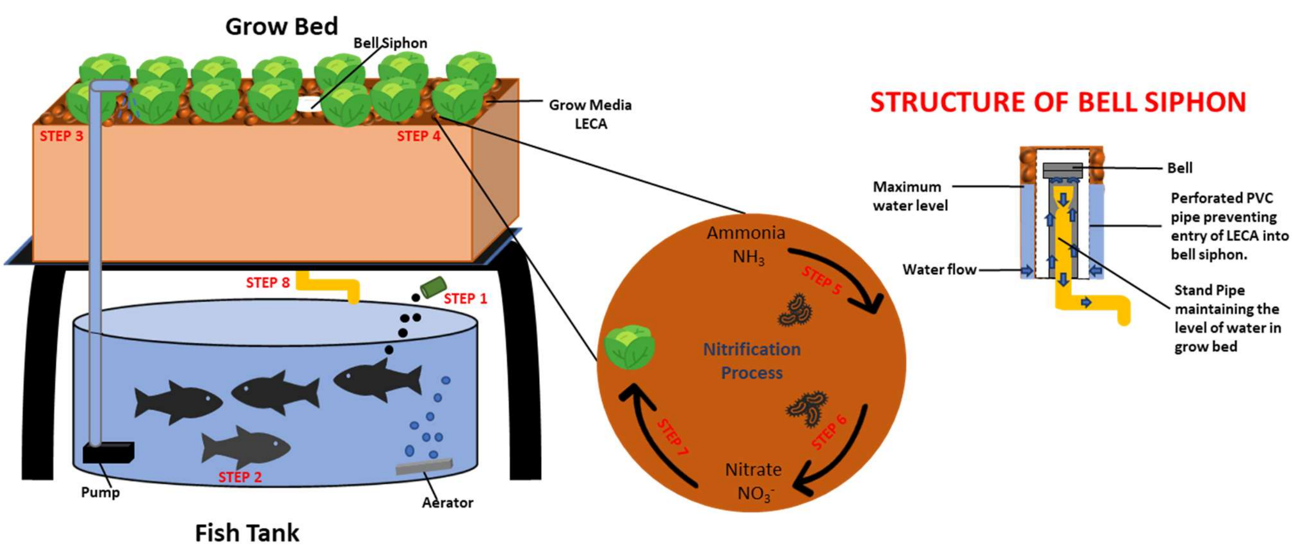


Figure 2 Flood and Drain Technique - Overview

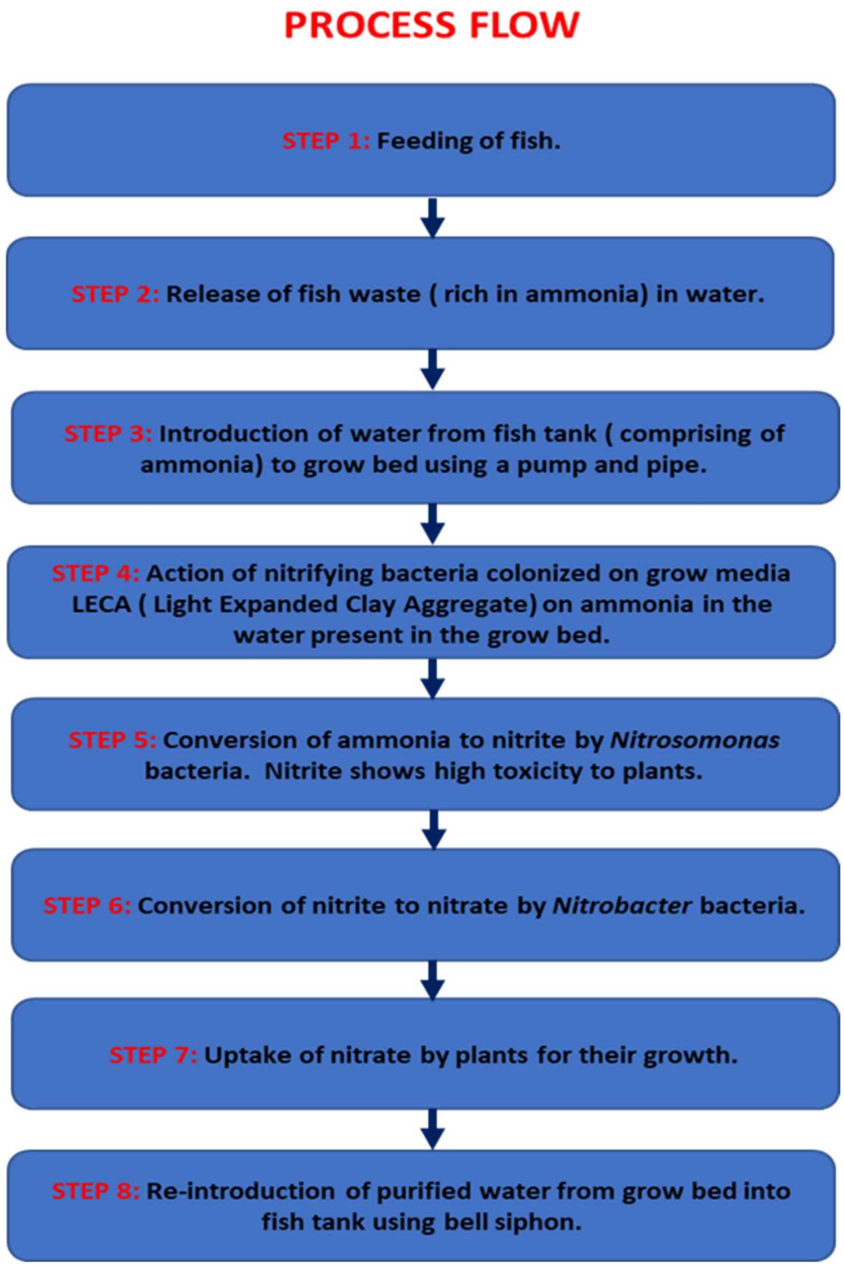


Figure 3 Process Flow - Flood and Drain Technique.

4.2 Nutrient film Technique (NFT)

The nutrient film technique of aquaponics utilizes horizontal tubes/channels for the passage of a shallow stream of water for supplying nutrients to plants placed within the horizontal tubes. The technique gets its name due to the formation of a thin film of nutrient-rich water within the tubes. The system necessitates a slope of around 1-4%, as the technique is gravity aided. The system comprises of under mentioned components:

Fish tank – to support the fish's growth.

- Radial filter – to remove the solid waste and uneaten food particles from the water of the fish tank. It comprises a horizontal pipe for the entry of water, followed by the striking of water to the outer pipe (attached to the lid) causing the settling of solid particles under gravity. Likewise, it utilizes a drainpipe to flush out the solid waste settled in the filter tank.
- Biological filter – comprises of grow media (bio-balls) promoting the growth of nitrifying bacteria. It utilizes air stone for enough oxygenation of water to support the growth of aerobic nitrifying bacteria and uses a drainpipe to flush out the sludge settled in the filter tank.
- NFT channels – They house the plants. Plants are placed within the holes of channels using the net cups. NFT provides a well-oxygenated zone to the roots of plants.
- Sump Tank – It forms the lowest point in the system and collects the treated water of the system.
- Pump – It aids the re-circulation of water from the sump tank to the fish tank.

The system overview is illustrated in figure 4.

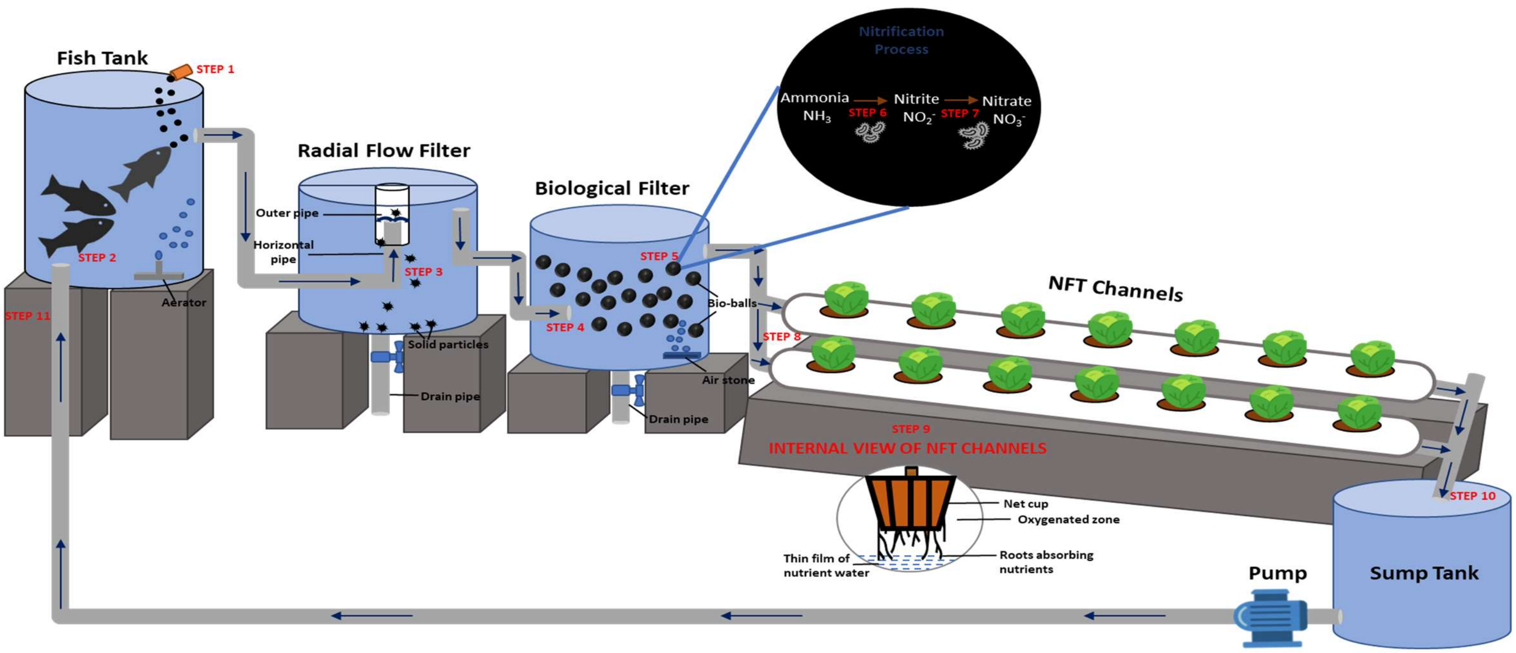
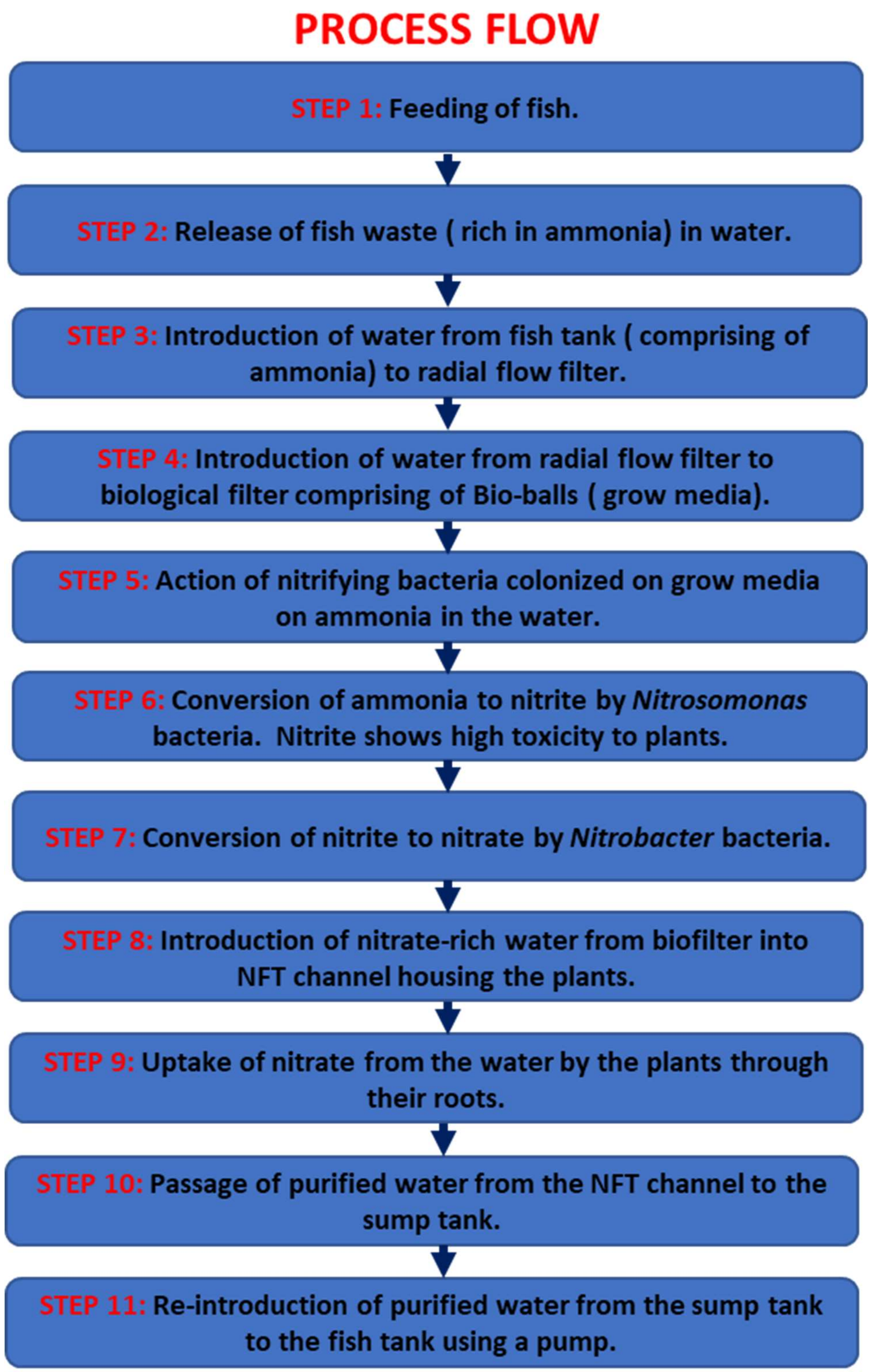


Figure 4 Nutrient Film Technique - Overview

The process flow of the aquaponic system utilizing the nutrient film technique is illustrated in figure 5.



5 Pathogens affecting the system

As indicated earlier in the paper, aquaponics plays a vital role in lowering food insecurities and providing a sustainable solution for food production. However, the control of pests in an aquaponic system forms one of the major challenges for a successful aquaponic system. A survey on EU Aquaponics Hub members, suggests only 40% of the aquaponic practitioners have some information about pests and plant pest control. (Villarroel, et al., 2016). Understanding the pathogens that may destroy the system becomes quite crucial for a sustainable aquaponic system.

Microorganisms are ubiquitous throughout the aquaponic system. They flourish on the fish bodies, filtration units, in water, and plants' parts. However, these microbes are the normal flora of each component mentioned and don't harm the system. Apart from nitrifying bacteria (given the utmost attention), several other microbes aid the process flow of the aquaponic systems. Characterization of system microbes can be undertaken by several modern sequencing technologies and taxonomy.

5.1 Plant pathogens

Like any other farming system, aquaponics also faces the threat of several plant pathogens. The humid/aquatic environment facilitates the growth of almost all pathogenic fungi and bacteria. For example, some fungi causing root rot such as Pythium spp. and Phytophthora spp. are highly adapted to such environmental conditions and produce motile zoospores. These zoospores actively circulate throughout the entire system rapidly, infecting the entire system. Some of the other pathogenic fungi found in the aquaponic system include *Fusarium spp.,* or species from the genera *Colletotrichum, Rhizoctonia*, and *Thielaviopsis*. A few examples of pathogenic bacteria include *Ralstonia, Xanthomonas, Clavibacter*, *Erwinia,* and *Pseudomonas*, as well as some viruses (Stouvenakers, Dapprich, Massar, & Jijakli, 2019). The pathogens find their entry into the system through the water supply, use of infected plants and seeds, contaminated growth media, insets (vectors of diseases and particle carriage), and system operators (tools and clothing).

Table 1. Illustrates a few plants and their pathogens.

Sr. No.	Plant Species	Phytopathogens	
		The pathogens identified by the symptoms in the aerial plant parts	The pathogens identified by the symptoms in the root part
1.	*Allium schoenoprasu*		*Pythium sp*
2.	*Beta vulgaris (swiss chard)*	*Erysiphe betae*	
3.	*Cucumis sativus*	*Podosphaera xanthii*	
4.	*Fragaria spp.*	*Botrytis cinerea*	
5.	*Lactuca sativa*	*Botrytis cinerea, Bremia lactucae*	*Fusarium sp., Pythium myriotylum*
6.	*Mentha spp.*	*Pythium sp.*	
7.	*Nasturtium officinale*	*Aspergillus sp.*	
8.	*Ocimum basilicum*	*Alternaria sp., Sclerotinia sp*	*Pythium sp.*

9.	*Pisum sativum*	*Erysiphe pisi*	
10.	*Solanum lycopersicum*	*Pseudomononas solanacearum, Phytophthora infestans*	

Source: (Stouvenakers, Dapprich, Massar, & Jijakli, 2019)

5.2 Fish Pathogens

Like plants, the fish are equally susceptible to several pathogens resulting in various fatal fish diseases. For example, bacterial catfish disease forms the major factor of system collapse, caused by *Aeromonas hydrophila* and *Flavobacterium columnare* (Chitmanat, Pimpimol, & Chaibu, 2015) Most bacterial fish diseases occur due to secondary infection. The factors responsible for the bacterial fish disease include; high stocking density, unsuitable transport, polluted water, and wound infection. It's been observed that *F. columnare* caused secondary infection of *A. hydrophila* resulting in more mortality.

Some of the bacteria get concentrated in the water recirculating systems which include, *Aeromonas spp., Vibrio spp., Mycobacterium spp., Streptococcus spp.,* and *Flavobacterium columnare* (P. E. Yanong, 2013). The recirculating system supports the growth of many pathogens and the spread of the disease. This is majorly caused due to higher densities of fish as compared to other culture systems, formation of biofilms and sediment, pathogens present in the mechanical and biological filters, sump tank, and a lower turnover of water.

Some of the bacterial fish diseases such as dropsy occurs due to *Aeromonas* infection. Similarly, *A. hydrophila* causes fin rot disease in fish (Kar, 2016), while *Streptococcosis* results from the *Streptococcus sp*. infection. Furthermore, tuberculosis in fish is associated with *Mycobacterium marinum* infection which results in necrotizing granulomas like tuberculosis, injury, and mortality in fish (Hashish, et al., 2018).

Besides the bacterial infections, the fish in the system are also prone to several fungal diseases such as White Cotton Saprolegnia by *Saprolegnia* spp. Similarly, some protozoans such as *Hexamita spp.* and *Spironucleus spp.*- causing *Hexamitosis*, adversely impact the fish health and the entire aquaponic system. *Piscinoodinium*, a dinoflagellate results in velvet/dust disease in fish. The fish in the aquaponic systems are likewise prone to parasitic worms such as *Lernaea* species, flatworms, leeches, and nematodes.

6 Methods of protection against pathogens

It has become a major challenge for aquaponics practitioners to prevent the infection and spread of the pathogen in the system, as no specific pesticides are developed for the aquaponic systems. Disinfection of water happens to be the only possible means to control the disease by decreasing the microbial load in the system. Disinfection can efficiently eliminate pathogens and can be applied to many parts of the system. The traditional physical methods utilized for killing the pathogens include; ultraviolet (UV) irradiation, media filtration, heat, sonication; while the chemical methods involve; chlorination and ozonation (Rivas-García, et al., 2020). However, these disinfecting procedures could have a negative impact on fish, plants, beneficial microorganisms of the system and could also harm human health, thus the use of these methods must be restricted.

6.1 Preventive treatments

As mentioned above the physical and chemical methods of treatment are highly restricted in the aquaponic systems, therefore several preventive measures need to be adopted for preventing and minimizing the proliferation of pathogens within the aquaponic systems. To limit the entry of pathogens into the system several preventive practices such as room sanitization, clothes sanitization, utilization of certified seeds, and other physical barriers are needed. Likewise, to evade the proliferation of phytopathogens, actions such as selecting resistant plant varieties, disinfection to avoid plant stress, better plant densities, tool disinfection, good plant spacing, avoidance of algae, and environmental management should be encouraged (Rivas-García, et al., 2020).

6.2 Biocontrol of pathogens

Biological control agents (BCA) utilized for aquaponics must have the following mentioned characteristics:

- Efficient at low concentration.
- Low nutritional requirements.
- Ability to survive under aquaponic conditions.
- Efficient against a large spectrum of plants as well as fish pathogens.
- Easy to prepare and use.
- Compatible with other treatments.
- No risk to fish, plants, other beneficial microorganisms, and humans.
- Genetically stable (if microorganisms).

Biological control agents comprise a group of antagonistic microorganisms that stops the development of several phytopathogens. *Pseudomonas* species are the most common biological agents researched in the hydroponic systems, which can also be applied to aquaponic systems. It has been reported that *Pseudomonas* spp. and *Bacillus* spp. could effectively control the plant pathogens by reducing induction, space, causing nutrient competition, and by producing secondary metabolites such as antibiotics and biosurfactants. Likewise, Lysobacter spp. are efficiently utilized as the biocontrol agents in aquaponic systems.

Few other organisms acting as a biocontrol in the soilless system include a range of bacteria such as *Pseudomonas, Burkholderia, Bacillus, Serratia, Actinomycetes*, fungi such as *Trichoderma, Penicillium, Gliocladium,* non-pathogenic *Fusarium*, and oomycetes such as *Pythium* (Vallance, et al., 2011). The antagonistic activities of these microorganisms involve competition for nutrients and space, parasitism, antibiosis, and systemic induced resistance. Similarly, the consortium of antagonist microbes could efficiently improve the biocontrol of pathogens in aquaponic systems. Microorganisms in the growth medium interact with the roots of the plants and accelerate the nutrients uptake, thereby, stimulating the plant growth and acting as an antagonist against the phytopathogens. The inhibitory effect of lactic acid bacteria against *P. ultimum* has been recently discovered (Sirakov , et al., 2016). Likewise, *Pseudomonas aeruginosa* strains exhibit antagonistic activity against the fish pathogen *S. parasitica*.

One of the strategies combines the inoculation of *Lysobacter enzymogenes* with chitosan. Chitosan improves the biocontrol efficacy of *L. enzymogenes* in the control of *P. apahidermatum* in cucumber in soilless systems. Chitosan utilized as a component of biocontrol strategy either served as a C and N source for the antagonist or stimulates antagonistic gene expression, or both (Postma, Stevens, Wiegers, Davelaar, & Nijhuis, 2009).

The lack of sterilization in the aquaponic systems results in a natural ecosystem where each biotic component interacts with each other to form a synergistic relation. In such a system, no single microbe can be dominant, therefore lowering the chances of causing the disease to fish or plants in the system.

6.3 Role of organic matter in biocontrol of pathogens

The organic matter in the system plays a critical role in the biocontrol of pathogens. In aquaponics, the source of organic matter comes from the water supply, unconsumed feeds, fish waste matter, organic plant substrate, root exudates, and plants residues. The heterotrophic bacteria occurring in the system utilize organic matter as the source of carbon and energy to proliferate. Likewise, humic substances present as dissolved organic matter forms another source of organic carbon for heterotopic bacteria. Although the abundance of heterotrophic organisms competes with nitrifying bacteria for space and oxygen (Stouvenakers, Dapprich, Massar, & Jijakli, 2019), they provide several benefits to the system and increases the system resistance against pathogens. Humic acids are observed to accelerate plant growth and safeguard the plant from abiotic stress. Additionally, the protein present in the water forms the source of nitrogen for plants, thereby, improving their growth and pathogenic resistance. The use of organic fertilizers or organic soilless media in aquaponics has been observed to have a positive impact on the resident microbiota, which in turn could control several plant diseases. Furthermore, the characteristics of the media stimulate the functionality and abundance of the microbial community, which could have a suppressive effect on the pathogens.

Pathogen suppression is likewise, linked to the use of organic amendments in aquaponics. For example, utilization of composts in soilless media illustrates suppressive effects. (Maher, Prasad, & Raviv, 2008).

Pseudomonas when enhanced and maintained in the system by adding customized carbon sources such as nitrapyrin-based product enhances its suppressive capabilities. (Pagliaccia, Ferrin, & Stanghellini, 2007).

One of the studies on pathogenic control in aquaponics proves the utilization of the following extract of seaweed (distributed in the Bulgarian Black sea) to inhibit the pathogens in aquaponics. The extracts include; ethanol (from *C. vagabunda*) against Bacillus cereus and *Aspergillus ochraceus*, methanol (from *C. rubrum*) against *E. coli, Bacillus cereus,* and *Candida albicans* (Sirbu, Negreanu–Pîrjol, Cadar, & Negreanu-Pirjol, 2015). However, future research on optimizing the doses of the extract to be utilized *in vivo* in aquaponics needs to be tested.

Though the information and research about the impact of organic matter on plant protection in an aquaponic system are limited, several instances discussed above illustrate the potential capacity of organic matter to support system-specific and plant pathogen-suppressive microbial communities.

7 Microbiology safety of aquaponics

Vegetables grown in the aquaponic systems are generally consumed raw. The World Health Organization and the Food and Agriculture Organization (FAO) have given top importance to minimizing the microbial contamination risk of leafy vegetables (FAO/WHO, 2008). Despite several good agricultural practices and laborious post-harvest techniques, there have been instances of the outbreak of foodborne *E. coli* O157:H7 from fresh produce in agricultural production systems (Kasozi, Abraham, Kaiser, & Wilhelmi, 2021). Similarly, various coliforms and bacteria are present throughout the aquaponic systems. However, several studies indicate a low risk of microbial contamination of the products from aquaponic systems, as equated to products obtained from soil-based systems. There have been many reports of internalization of several foodborne pathogens in fresh fruits and vegetables, however, there have been no reports suggesting the presence of human pathogens in aquaponics products yet. Several studies have indicated a relatively lower concentration of microbes on aquaponic lettuce as compared to lettuce grown on soil, with no detectable *E. coli* coliforms, *E. coli* O157:H7, or *Salmonella spp*. Additionally (Schmautz, et al., 2017) reported low manifestation of *Aeromonas* (only 0.25% of the total bacterial load) in fecal samples of tilapia cultured in aquaponics that had lettuce growing on a floating raft system. The effect of bacteria on the crop was not investigated but the fish were found to be healthy.

8 Conclusion

Aquaponics is a decent answer to the food crisis witnessed globally. The symbiotic relationship between the plants, bacteria, and fish provides a complete balance of the system leading to a successful system. Aquaponics assume several different designs, however, with the same fundamental components. However, like any other agricultural system, aquaponics is also susceptible to pathogens which ultimately causes the system to collapse. Many physical and chemical control techniques are not suited for aquaponic systems. Therefore, the biological methods, utilizing biological control agents eliminate most of the plants as well as fish pathogens from the system. However, the development of specific biopesticides for aquaponics, optimizing the doses of BCA, evaluating the impact of BCA on other beneficial microbes, the role of earthworms, and their interaction with microbial communities are some of the areas of research and development in aquaponic systems.

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