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Assessment of Aquaponics Biofilter Performance in Reducing Dissolved Solids Concentration

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Abstract*—Aquaponics systems allow simultaneous growth between vegetables and fish with the use of aquatic products. This process is due to the presence of beneficial microbial communities such as nitrifying bacteria. Numerous water quality problems can be addressed by improving the conversion efficiency of biological filtration systems. Maintaining parameters including increased ammonia and nitrite concentration, organic matter accumulation, and decreased levels of dissolved oxygen are imperative to maximize system productivity. The pilot-scale model of the aquaponics system features two independent systems: the control (with biofilter), and the experimental (without biofilter). The media in the biofilter is as follows: an aeration system (for oxygen supply), and a centralized sensory chamber (to facilitate automatic monitoring of pH, temperature, dissolved oxygen, and turbidity). This study assessed the performance of an aquaponic setup with a biofiltration system in terms of reducing the concentration of dissolved solid particles in the water. The correlations of ammonia, nitrate, and nitrate concentrations with turbidity were explored. The turbidity was monitored using a turbidity sensor. To test ammonia, nitrite, and nitrate, solutions were dropped into water samples, whose developed color was compared to a color chart. The system must operate in conditions that cater to the collective growth and development of the fish, plants, and nitrifying bacteria. The plant crop utilized in this study is mint (Mentha spicata), while the fish used was the Red Tilapia (Oreochroomis aureus x Oreochromis mossambicus). Ammonia levels were found to be substantially connected with nitrate levels, and both parameters were shown to be inversely correlated with turbidity. Turbidity in water may be caused by active microorganisms or algae that may metabolize ammonia and nitrate.

***Keywords*—innovative agriculture, soilless agriculture, ammonia, nitrate, turbidity**

I. INTRODUCTION

Industrialization threatens the future of agriculture with issues such as the global food crisis, pollution, and reduced resources—the gradual solution could be achieved by simple modern technologies such as aquaponics.

Aquaponics is an environmentally sustainable agricultural technology that enables year-round production of high-quality fish and vegetables, relying on the microbiota composition and health of the system. The overall productivity of aquaponics systems depends on technical parameters such as water quality, pH, and flow rates, which facilitate microbial activities in nitrification and remineralization processes [1]. Aquaponics, also a technique of food production that blends fish farming without soil plant development, is gaining popularity and attention as an essential and more sustainable means of creating food. It combines the merging of fish and plants into a recirculating ecosystem that uses natural nitrifying bacteria to turn fish wastes into plant nutrients [2].

Ammonia nitrogen, the most preferred nutrient for plant growth, is a product of aquatic animals' nitrogenous waste. A biofiltration system built upon these concepts helps to fully maximize the mutualistic relationship that can be found between water, fish, nitrogenous waste, and plant growth. It functions in such a way that it extracts fish excrement and undergoes the process of nitrification, converting ammonia to

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Fig. 1. Actual Aquaponics Setup: Control (Left) and Experimental (Right) Systems

nitrite and then to nitrate. The bacteria present in this process, *Nitrobacter* and *Nitrosomonas*, are then used to aid in plant growth [3]. The biofilter can be integrated into the system using existing surfaces or implemented as a separate unit with porous media, depending on the specific aquaponic configuration and the requirement for supplementary biofiltration [4]. Monitoring the levels of total dissolved solids (TDS) in biofilter aquaponics systems provides valuable information about water quality, offering insights into the salinity and overall health of the system. [5] Understanding the correlation between TDS and other parameters allows aquaponic practitioners to estimate TDS concentrations, enabling effective assessment and management of dissolved solids and their impact on the biofilter's performance. However, precise measurements of TDS may require laboratory analysis using gravimetric methods to ensure an accurate evaluation of water quality in biofilter-based aquaponic systems [6]. In the context of water quality parameters, one research study was conducted to explore the potential of biochar as a filtration medium for reducing turbidity in aquaponics systems with high concentrations of dissolved solids. Optimization of biochar filter bed height and loading rates were found to enhance the removal of suspended particles and turbidity, emphasizing the potential of biochar-based filtration as a viable approach for improving water quality in aquaponics systems with high dissolved solids concentrations [7].

Mainstream production of these systems could create notable change in the global food crisis and lack of land and resources. It could also promote better economic openings, especially for third-world countries to compete with an edge against the rise of industrialization. Several promising studies have previously demonstrated that aquaponic plant production may be as high as hydroponics even with lower nutrient concentrations, such as nitrogen, phosphorus, and potassium (NPK) when employing recirculating water [8]. Due to the existence of beneficial microbial populations such as nitrifying bacteria, this is achievable. Given that the establishment of these microbial communities is dependent on various environmental characteristics such as pH, temperature, total ammonia nitrogen (TAN), dissolved oxygen (DO), and turbidity, there must be a mechanism in place to keep these values within an appropriate range. The upkeep of these parameters will aid in the productivity of the aquaponic system and its subsystems.

An automated aquaponic system with a biofiltration system was designed and developed. In this study, the performance of an aquaponic setup with a biofiltration system was assessed in terms of reducing the concentration of dissolved solid particles in the water. The correlations of ammonia, nitrate, and nitrate concentrations with turbidity were explored. The turbidity was monitored using a turbidity sensor.

Turbidity is a water quality measure induced by suspended particles. Suspended particles in water scatter light in all directions, causing the water to appear cloudy or muddy [9]. Algae, fine organic and inorganic materials, clay, and silt deposits, as well as other microscopic organisms, constitute the suspended particles in the water. Organic particles should be minimized since their decomposition lowers the level of DO and produces harmful byproducts including methane (CH_4) and hydrogen sulfide (H_2S) [10]. High levels of turbidity require higher use of oxygen. The oxygen will only come from the dissolved oxygen in the water. The fluctuation of DO concentration in aquaponics and aquaculture is a direct outcome of many physical, chemical, and biological processes such as photosynthesis, plankton and plant respiration, fish respiration, sediment-oxygen demand, and air-water gas transfer diffusion [16]. Phytoplankton, zooplankton, bacteria, and fungus are examples of free-floating moving creatures suspended in recirculating water. All plankton use oxygen, while phytoplankton creates oxygen throughout the day because of photosynthesis. The consumption and production of DO both contribute to the system's fluctuating DO concentration. The oxygen requirements of fish vary depending on the species and its activity. Sediment oxygen demand relates to microbial processes in the sediment-water interface, such as nitrification. Organic matter decomposition, such as ammonia and feces, necessitates the use of oxygen. The interchange of water molecules at the air-water interface is referred to as air-water diffusion. During water flow, turbulent flow enhances the transport of oxygen from air to water. Table 1 shows the different processes in the aquaponics systems that affect the concentration of dissolved oxygen in the water. Low DO levels are accountable for more fish kills, directly or indirectly, than all other problems combined [17].

Table 1. Processes that Affected Dissolved Oxygen Levels

Component	**ppm O_2 per day**	**Factors Affecting Rate**
INPUT		
Photosynthesis	0 – 40	Phytoplankton Biomass Phytoplankton Species Sunlight Turbidity Water Temperature
Air-water Diffusion	0 – 6	Degree of Unsaturation Wind Speed
LOSSES		
Plankton Respiration	0 – 40	Phytoplankton Biomass Phytoplankton Species Water Temperature
Fish Respiration	0 – 12	Fish Biomass Fish Size Fish Activity Feeding Interval Water Temperature
Sediment Oxygen Demand	0 – 10	Sediment Organic Matter Oxygen Content of Overlying Water Sediment Chemistry Water Temperature
Air-water Diffusion	0 – 6	Degree of Supersaturation Wind Speed

II. METHOD

A. Description of Aquaponic Setup

Figure 1 shows the actual aquaponic setup used in the experiment. The design of the control system consists of the following: sensors, controllers, pumps, and the aeration system. The setup measures 2 m in length, 0.6 m in width, and 2.2 m in height and is supported by a metal frame. The metal frames are made of slotted angle bars, which are more affordable than tubular metal. The grow beds and fish tanks are made of a 6-mm concrete fiber cement board that is joined with high-viscosity concrete epoxy. The grow beds are 1 m long, 0.6 m wide, and 0.2 m tall, with a total capacity of 0.12 m^3. Meanwhile, the fish tanks are 0.75 m long, 0.6 m wide, and 0.35 m tall, with an overall volume of 0.16 m^3. A mesh netting is also constructed around the upper portion to protect the grow beds from bird or insect attacks. A polyethylene layer with anti-UV properties covers the roof.

The biofilter media to be used is gravel, known as one of the naturally occurring biofilter media. Gravel is a rock that is an excellent material for biofilter media because of its low cost and availability. In other types of filters, like submerged filters and trickling filters, it is common to utilize gravel as the preferred choice of material. The surface area of gravel can vary depending on its size, ranging from 280 m^2/m^3 for pea gravel with a diameter of approximately 14.5 mm, to 69 m^2/m^3 for medium gravel with a diameter of around 25 mm, to 39 m^2/m^3 for large gravel with a diameter of approximately 102 mm. In this research, gravel sizes ranging from pea to medium were employed.

B. Ammonia, Nitrite, and Nitrate Testing

Using the API Freshwater Master Test Kit, the concentrations of ammonia, nitrite, and nitrate in the water were measured. Various solutions, test tubes, and a color chart are provided in this package. The color chart provides the necessary information to determine the amount of ammonia, nitrite, and nitrate in each solution.

Fig. 2. Comparing the results of the ammonia, nitrate, and nitrite test to the color chart.

Ammonia, nitrite, and nitrate were measured using package instructions. Figure 2 shows each solution's color is allowed to develop before the test results are interpreted by comparing the color to the specified color chart. The tubes are viewed against a white background in a well-lit environment. The concentration of the solution is indicated by the solution's color closest to the color on the chart. The first test tube is for ammonia testing, the second test tube is for nitrite testing, and the third test tube is for nitrate testing. Each of the fish tanks and grow chambers must undergo the same procedure.

C. Turbidity Testing

The turbidity sensor, located in the system's center of arrangement, monitors the water's dissolved solids. The turbidity sensor in the sensory chamber is seen in Figure 3. Since there is only one testing chamber in the whole aquaponic arrangement, each chamber's testing is done in a cycle. Each cycle lasts around 7 minutes and comprises filling the sensory chamber with water, recording the sensor measurements, and emptying the water from the chamber. The aquaponic systems include a total of six chambers, therefore measuring the complete system takes 42 minutes.

Fig. 3. Turbidity Sensor in the Sensory Chamber

III. RESULTS AND DISCUSSION

A. *Turbidity Results*

Turbidity indicates the presence of suspended particles in water, which originates from sources like fish feces, leftover fish feeds, etc. Keeping an ideal turbidity level is essential because the decomposition of these particles utilizes oxygen in the water. In Figures 4 and 5, the turbidity levels are shown for the fish tank in both the control and experimental setups. It is apparent that the turbidity was greater in the fish tank of the control setup matched to the experimental setup.

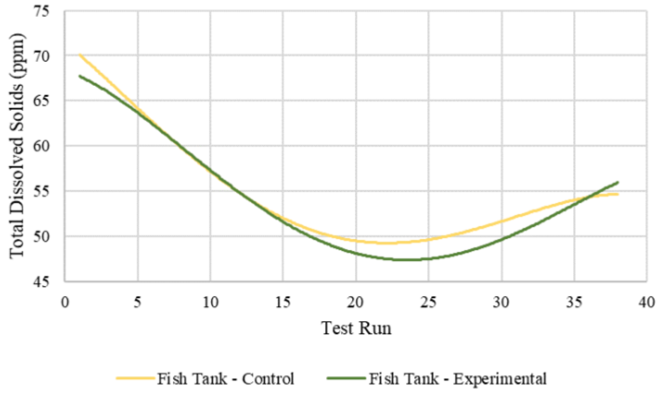

Fig. 4. Turbidity Comparison of the Control and Experimental Fish Tanks

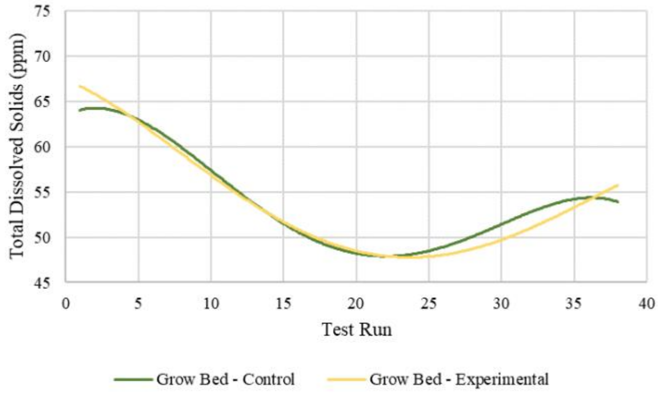

Fig. 5. Turbidity Comparison of the Control and Experimental Grow Beds

In the control setup, the turbidity difference between the fish tank and the grow bed is higher compared to the experimental setup. This indicates that the filtration system in the experimental setup is more efficient at removing suspended particles from the water. The filtration system effectively eliminates larger particles, resulting in a negligible difference in turbidity between the fish tank and grow bed. However, despite the removal of larger particles, finer dissolved particles remain present in the water, causing it to become turbid.

B. *Ammonia, Nitrite, and Nitrate Correlation with Turbidity*

Figure 6 depicts the correlation between ammonia, nitrate, and turbidity in the fish tank of the control setup. The graph demonstrates that only ammonia and nitrate are positively correlated, as it garnered 0.80. Meanwhile, ammonia and turbidity have a strong negative correlation. Similarly, nitrate and turbidity are also negatively correlated.

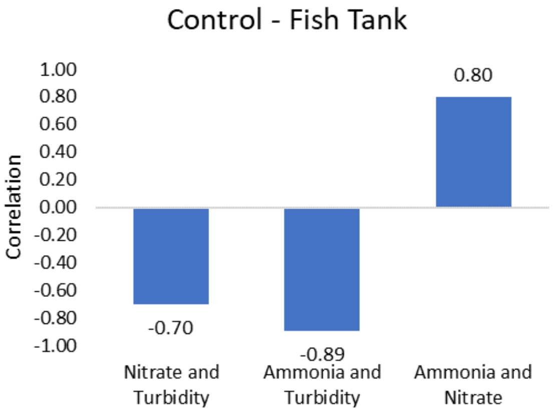

Fig. 6. Ammonia, Nitrate, and Turbidity Correlation in the Control Set up of the Fish Tank

Figure 7 depicts the correlation between ammonia, nitrate, and turbidity in the grow bed of the control setup. Like the fish tank in the control setup, the graph depicts that ammonia and nitrate are positively correlated at 0.73. The relationship between ammonia and turbidity in this setup is slightly negative, in contrast with the strong negative correlation in the fish tank. On the other hand, nitrate and turbidity garnered 0.13, demonstrating a slight positive correlation.

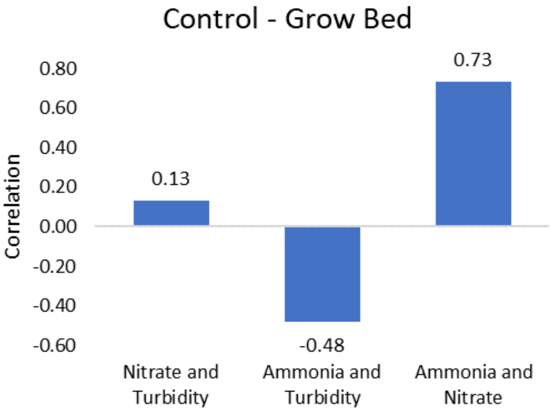

Fig. 7. Ammonia, Nitrate, and Turbidity Correlation in the Control Set up of the Grow Bed

When comparing the control and experimental setup of the fish tank, the correlation between ammonia, nitrate, and turbidity is similar. Figure 8 depicts that ammonia and nitrate are consistently correlated, at 0.77. Furthermore, ammonia and turbidity are negatively correlated, garnering a score of -0.23. This result is consistent with nitrate and turbidity as it earned a negative correlation of -0.53. The difference between the control and experimental setup in the fish tank is only the degree of correlation, ranging from a slight negative to a strong negative.

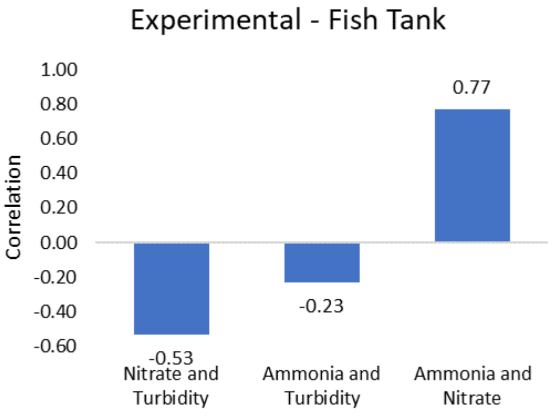

Fig. 8. Ammonia, Nitrate, and Turbidity Correlation in the Experimental Setup of the Fish Tank

Lastly, Figure 9 depicts the correlation between the three water parameters in the grow bed of the experimental setup. Among all four setups, this setup produced contrasting results. Instead of a strong positive correlation between ammonia and nitrate, it attained a slight positive correlation of 0.42. Its correlation between ammonia and turbidity remained constant with a slight negative correlation of -0.45. Dissimilarly, the correlation between nitrate and turbidity in the experimental setup of the grow bed is contrastingly different from that of the control setup.

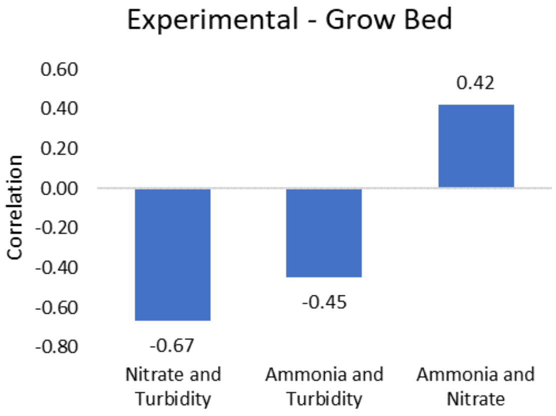

Fig. 9. Ammonia, Nitrate, and Turbidity Correlation in the Experimental Setup of the Grow Bed

From all the setups, it can be noted that consistently, nitrate and ammonia are positively correlated. On the other hand, turbidity is generally negatively correlated with either ammonia or nitrate. The first observation can be explained by the fact that nitrifying bacteria convert ammonia into nitrate, and the higher levels of nitrate are simply a product of higher nitrification rates due to the ammonia's abundance.

The second observation, however, is more complex. One possible reason is that the turbidity may arise from any undissolved particles in the setup, which includes algae and bacterial cells. It was frequently observed in the control setup, for example, that the water column contains algae precipitate upon centrifugation. Therefore, the presence of algae which may also consume the nitrate and ammonia can explain the consistent negative correlation between turbidity and nitrate/ammonia levels. When the setup is more turbid, there are more living microorganisms present in the water that can consume nitrate and ammonia.

Understanding the flow and transformation of nutrients and the physiochemical properties of water will increase its productivity. Larger-scale cultivation systems would be exponentially radicalized through the implementation of biofiltration systems. Biofilters can utilize the nitrogen present in the system in the form of ammonia. Moreover, the water reuse efficiency will increase. Typically, a stand-alone aquaculture system will require 2,500 to 375,000 L of water to grow 1 kg of fish. With the recycling of water, water usage can be lowered to less than 100 L of water to grow the same number of fish [19].

The technical limitations of this biofiltration system include its initial difficulty in its set-up, partly due to its sensitivity and physical components. Each biofilter, especially those made for the purpose of individual farmers, may be arbitrarily different from each other depending on the kind of fish, amounts of ammonia/nitrite/nitrate, reagents, location, and size, among others. These challenges include the need for a reliable data collection infrastructure to gather real-time information on water quality, system performance, and environmental conditions.

In terms of its AI component for the user interface, it may be difficult to program a code that can sustain itself with little to no human interference. Preliminary models may be tested and improved upon until it reaches a sustainable and independent course. Developing accurate AI models for biofiltration systems requires an understanding of complex biological and chemical processes. Integrating AI algorithms with existing control systems to automate and adjust parameters is a challenge. Overall, successful implementation of AI in biofiltration systems requires addressing data collection, model development, and control and automation challenges.

IV. CONCLUSION

Biofilters can utilize the nitrogen present in the system in the form of ammonia. These challenges include the need for a reliable data collection infrastructure to gather real-time information on water quality, system performance, and environmental conditions. Integrating AI algorithms with existing control systems to automate and adjust parameters is a challenge. Developing accurate AI models for biofiltration systems requires an understanding of complex biological and chemical processes.

In this study, the performance of an aquaponic system in terms of dissolved solids removal was evaluated. The aquaponics setup used in this study was composed of two separate systems, one with a biofilter and one without. The biofilter provides the filtration system and increases the amount of surface area available for nitrifying bacteria to colonize. Certain water parameters were tested every 7 minutes, which is enough time for water to fill the sensory chamber and then drained out. The quantities of ammonia, nitrite, and nitrate were measured during the experiment to determine the effect of installing a biofilter. In general, it was observed that the ammonia levels are strongly correlated with nitrate levels, and both parameters are negatively correlated with turbidity. The turbidity may be attributed to active microorganisms or algae present in the water that can metabolize ammonia and nitrate.

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REFERENCES

[1] G. M. Burnell, B. Kotzen, and S. Goddek, Aquaponics Food Production Systems. Saint Philip Street Press, 2020.

[2] R. Sallenave, “Important Water Quality Parameters in Aquaponics Systems,” College of Agricultural, Consumer and Environmental Sciences, New Mexico State University, 2016.

[3] L. Kessel, P. Flesner, J. Andresen, D. Erngaard, B. Tendal, and J. Hjortdal, “Antibiotic prevention of postcataract endophthalmitis: a systematic review and meta-analysis,” Acta Ophthalmol., vol. 93, no. 4, pp. 303–317, 2015.

[4] R. Nelson, “Aquaponic Equipment the Bio Filter,” Aquaponic Equipment The Bio Filter, vol. 1, no. 48, pp. 22–23, 2008.

[5] M.F. Taha, G. ElMasry, M. Gouda, L. Zhou, N. Liang, A. Abdalla, D. Rousseau, Z. Qiu, “Recent Advances of Smart Systems and Internet of Things (IoT) for Aquaponics Automation: A Comprehensive Overview. Chemosensors 10, 303. https://doi.org/10.3390/chemosensors10080303, 2022.

[6] A. F. Rusydi, “Correlation between conductivity and total dissolved solid in various type of water: A review,” IOP Conf. Ser. Earth Environ. Sci., vol. 118, p. 012019, 2018.

[7] Z. Khiari, K. Alka, S. Kelloway, B. Mason, and N. Savidov, “Integration of biochar filtration into aquaponics: Effects on particle size distribution and turbidity removal,” Agric. Water Manag., vol. 229, no. 105874, p. 105874, 2020.

[8] H. W. Palm et al., “Towards commercial aquaponics: a review of systems, designs, scales and nomenclature,” Aquac. Int., vol. 26, no. 3, pp. 813–842, 2018, doi: 10.1007/s10499-018-0249-z.

[9] M. P. C. Agency, “Turbidity: Description, Impact on Water Quality, Sources, Measures-,”2008.

[10] Z. Khiari, K. Alka, S. Kelloway, B. Mason, and N. Savidov, “Integration of Biochar Filtration into Aquaponics: Effects on Particle Size Distribution and Turbidity Removal,” *Agric. Water Manag.*, vol. 229, no. August 2019, p. 105874, 2020, doi: 10.1016/j.agwat.2019.105874

[11] M. Sikora, J. Nowosad, and D. Kucharczyk, “Comparison of different biofilter media during biological bed maturation using common carp as a Biogen donor,” Appl. Sci. (Basel), vol. 10, no. 2, p. 626, 2020.

[12] J. H. Tidwell, Aquaculture Production Systems: Tidwell/aquaculture production systems. Ames, IA: Iowa State University Press, 2012.

[13] A. Ciji and M. S. Akhtar, “Nitrite implications and its management strategies in aquaculture: a review,” Rev. Aquac., vol. 12, no. 2, pp. 878–908, 2020.

[14] J. Davidson, C. Good, C. Welsh, and S. T. Summerfelt, “Comparing the effects of high vs. low nitrate on the health, performance, and welfare of juvenile rainbow trout Oncorhynchus mykiss within water recirculating aquaculture systems,” Aquacultural Engineering, Volume 59, Pages 30-40, ISSN 0144-8609, https://doi.org/10.1016/j.aquaeng.2014.01.003, 2014.

[15] J. E. Rakocy, D. S. Bailey, R. C. Shultz, and J. J. Danaher, “A commercial scale aquaponic system developed at the University of the Virgin Islands,” In Proceedings of the 9th International Symposium on Tilapia in Aquaculture (pp. 336-343). Shanghai, China: AquaFish Collaborative Research Support Program, 2011.