Design And Development of Integrated Aquaponics System Combined with Decentralized Hydroponics Wastewater Management

Abdullahi isyaku kankia[1] , Valsa Remony Manoj[2]*

[1] PhD Research Scholar Department of Biotechnology, Vel Tech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology, No.42, Avadi-Vel Tech Road, - Avadi High Rd, Vel Nagar, Chennai, Tamil Nadu 600062 Chennai India.

*[2] Associate professor Department of Biotechnology, Vel Tech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology, No.42, Avadi-Vel Tech Road, - Avadi High Rd, Vel Nagar, Chennai, Tamil Nadu 600062, hodbiotech@veltech.edu.in

Abstract

This study aims to design a couple of aquaponics systems for wastewater management. Six vertical reactors were designed, each containing hydroponic net cub holes with a surface area of 0.0399 m2. The fish effluent was treated in the biofilter, which was designed locally using a sponge filter, ceramic rings, and bio balls. and the net was used as a mechanical filter to remove the uneaten feed given to the fish, a 20-liter biofilter was built, and the flow rate of the filtrate (Q_{BIO}) was kept constant at 3250 ml/min, which is the same as the flowrate of holding tank 1 ($Q_{BIO} = Q_{H1}$ = 3250 ml/min), the hydraulic retention time (HRT) was 8 minutes and 33 seconds, which was maintained constant throughout the experiment because a constant flow rate was maintained in the reactor **(Q_R)** at 2400 ml/min. The growth rate of algae in the fish tank was observed, this was determined by taking an OD with a spectrophotometer weekly as the growth rate increased and the pH dropped on average from 7.1 to 6.3 in the fish tank. In conclusion, the design flow rates and HLR influence wastewater management, and algae growth in the fish tank influences the decrease in pH of the fish effluent.

Keywords: Aquaponics, biofilter, hydroponics, Flowrate, Holding tank, Algae

Introduction

A method called aquaponics combines hydroponics and aquaculture in a single system. While hydroponics is the method of growing plants without soil, aquaculture is the practice of raising fish and other aquatic animals(Cheong et al., 2018), It is the modernization of hydroponics in which aquaculture is added; all this is done in a controlled environment, and the rationale behind this is to boost nutrients in the plant that are coming from the fish as nutrient waste. These nutrients coming as waste will be connected to the plants as an input subscript. This plan will remove ammonia, phosphate, organic carbon, potassium, and organic carbon, and clean water will return to the fish. The roots of the plants provide enough surface area for the bacteria to absorb BOD from the water; from the root zone, the concentration of dissolved oxygen (DO) may reduce due to the removal of BOD by the roots using oxygen(Colt et al., 2021a). Aquaponics requires a balanced growth condition for both plants and fish; a high amount of ammonia produced by the fish can be a problem and can cause fish death; microalgae is a naturally occurring microorganism in aquaponics; algae can be used under controlled conditions in an aquaponics system to improve water quality and remove nutrients; it will generate oxygen; polyunsaturated fatty acids will be produced by the algae; and it also increases resilience. When used efficiently in a controlled environment, algae can be used to: (1) remove additional nutrients produced by fish, resulting in improved water quality. (2) The pH drop caused by nitrification will control (3) the addition of more oxygen to the system, and (4) the fish will consume a polyunsaturated fatty acid derived from algae (Addy et al., 2017). Despite research and private investment, aquaponics is still only developing at a very modest pace despite all the advantages, Lack of guidance in choosing the best technology is the key issue with this approach, there are numerous methods to use aquaponics (Gibbons G.M). Following are the categories of persons who employ aquaponics (Hager,J.) • As a hobby • For the improvement of the economy and communities • For the production of more food • For personal use • As a learning tool in the collection

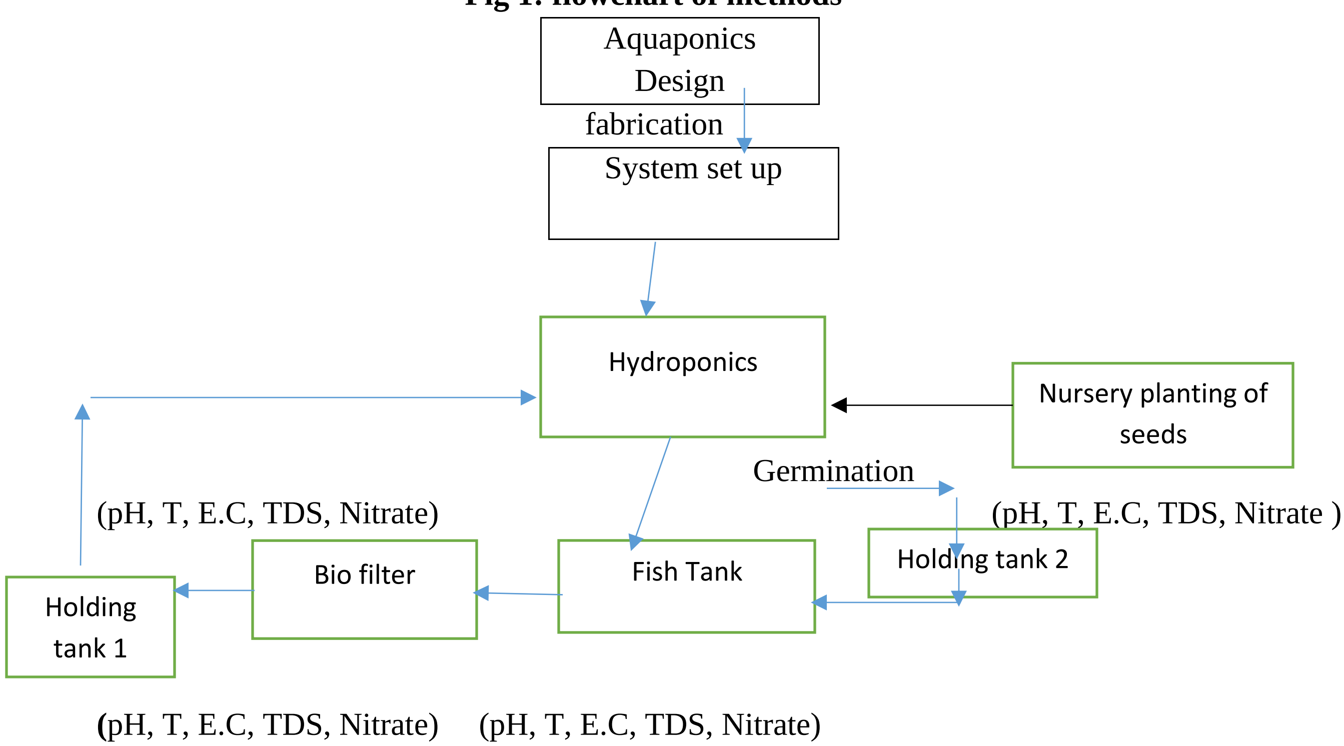
To improve crop growth and yield in aquaponics, proper system design is required, including the flow rate of the biofilter, holding tanks, flow rate through the reactor, and determination of the optimum HLR for wastewater management. The main objectives of the study were. The main objectives of the study were

1. Obtaining design parameters for aquaponics
2. Effects of Temperature and pH in Nitrate Nitrogen removal efficiency
3. Effect of HLR in waste water management
4. Effect of algal growth for waste water management

MATERIAL AND METHODS

The methods of the process are shown in Fig1

Fig 1: flowchart of methods



The system was constructed at the biotechnology department in Vel tech university Chennai. A 200-liter tank was used as a fish tank; a 10-cm hydroponic cup was used; and a 40-liter tank with ceramic rings, bio-balls, a sponge filter, and a mechanical filter was used for filtration and solids removal. Two 20-liter tanks were used as holding tanks 1 and 2. The fish tank, filtration tank, and holding tank 1 and 2 were connected by 25mm polyvinyl chloride (PVC) pipes, and the holding tank 1 was connected to the reactor by 20mm irrigation pipes. The inlet and outlet of the reactor were connected to the fish tank for effluent recycling, and the water flow was controlled by 25mm valves connected at the inlet hydroponics. There were 20 Siluriformes species used in the fish tank, the waste-water from the fish tank was gravity-fed through the filter tank and the holding tank 1; a submersible pump was used to vertically pump the waste-water from the holding tank 1 to the reactor, then flow through the holding tank 2, then pump back to the fish tank. The effluent is continuously recycled through the system.

Solid waste removal and biofilter design

A net with a mesh size of 1.2 mm is used as a mechanical filter to remove solid waste. Solid waste and uneaten feed combined with fish sludge create this thick, soft, and muddy residue that will remain precipitated while those that dissolve provide nutrients to the plants (Zhang Hong *et al*2021*)* Elements like potassium which is highly soluble in water, some elements are in solid forms like iron, uranium, copper, and chromium (Strauch, S.M. *et al* 2018). A system of fish production where water treatment is done is called a "recirculating aquaculture system" (RAS). This system includes: 1) bacterial flocs, uneaten feed, and fish faeces that are in solid form and will be trapped in mechanical filters. 2) Ammonia, which is excreted by fish, needs to be oxidised to nitrate by nitrifying biofilter. 3) Dissolved carbon dioxide expelled by fish must be removed, and oxygen must be added to the nitrifying bacteria and fish. (Espinal, C.A. and Matulić, D 2019)

Water-Parameters Measurement

According to the method adopted by (Yang & Kim, 2020) the water parameters such as EC (electrical conductivity), temperature, TDS, and pH were measured daily before giving feed to the fish. The parameters were taken from the fish tank, the bio filter, holding tank 1, and holding tank 2. The behaviour of the fish and its metabolic activities all depend on the *temperature (Deswati et al., 2020) (Ujjania et al., 2021),* As the temperature increased, the microbes would act on the organic matter, increasing its decomposition (*Deswati et al. – 2020)* , the more decomposition occurs, the more algae grows, nitrogen and phosphate support the growth of algae. Absorbance was used to measure the growth of the algae culture in the bioreactor; a spectrophotometer was used at 750 nm *(B978-0-12-817536-1.00009-6.Pdf, n.d.)*. In this experiment, the pH was maintained between 6-7, as reported by *(Sallenave).* The temperature and the pH of the water will both affect the ratio of NH_3 to NH_4^+ in the water at any given time. At a pH of 7.0 or lower, the majority of ammonia (> 95% concentration) will be in the non-toxic form (NH_4^+). As the pH rises, this ratio of toxic ammonia to non-toxic ammonia will significantly rise

Experimental Design

The basic design of aquaponics follows the same pattern, in which the idea of the whole design involved the feeding of plants from the waste produced by farmed fish or other aquatic creatures; they supply the nutrients for plants grown hydroponically, and the water coming out of the plant is purified using this technique. Using this technique, an integrated system was designed *(Cheong et al., 2018),* the research design includes four flow rates for the biofilter as well as holding tanks 1 and 2,the hydraulic retention time (HRT) of holding tank 2, which received reactor effluent, was measured. The systems are designed as a replica of the recirculation system; Bio filter is designed to collect the outlet water from the fish tank is treated to reduced organic matter from this water *(Stone, N.M el al)*

Percentage Nitrate- Nitrogen Removal efficiency

Using spectrophotometric analysis as proposed by *(APHA Method 4500-NO3),* before feeding the fishes each week, 20 ml of samples from holding tanks 1 and 2 were collected and analyzed. Nitrate-nitrogen removal was measured using a spectrophotometer at 220 nm, and the percentage removal efficiency was calculated using the equation.

Percentage Nitrate-Nitrogen Removal

$$= \frac{Nitrate\ In - Nitrate\ out}{Nitrate\ in} \times 100$$

Where $Nitrate_{in}$ was the amount of Nitrate(mg/l) for the holding tank 1 (H_1) which was the tank that supplied effluent to the reactor (plant beds), while the $Nitrate_{out}$ was the amount of Nitrate for the holding tank 2 (H_2) which was the tank that collects the effluent from the reactor

Percentage efficiency of BOD Removal

The amount of dissolved oxygen consumed by microbes during the oxidation of reduced compounds in water and waste is known as biochemical oxygen demand (BOD).(Penn, n.d.),according to the method developed by (*APHA Method 4500-NO3 Standard Methods for the Exa.Pdf*, n.d.) the BOD removal efficiency was calculated .The development of waste materials in the root zone can lead to the development of illness and anaerobic conditions. The presence of higher amounts of biodegradable organic compounds exacerbates the decrease in dissolved oxygen (BOD). In addition to physically reducing water flow through the root zone, the buildup of particulates can also directly consume dissolved oxygen.(Colt et al., 2021b)

Algal growth in the fish Tank

The optical density was taken at 640nm up using a UV-visible spectrophotometer as proposed by (Mirón et al., 2000) ,the growth of algae in the fish tank was monitored each week. The presences of algae in the fish tank

Results

Ceramic rings with a specific surface area for beneficial bacteria were purchased from an aquarium store, known as: Venus Aqua has a height of 2 cm and a width of 1.5 cm. The aquarium stores also provided a sponge filter with the following specifications: Type Fabric-Cotton, Color: White, Size: Approx. 100x13.5x3cm/39.37x5.31x1.18inch, Package:1 Piece Filter Sponge

Fig 1: Percentage Nitrate- Nitrogen Removal efficiency

Fig 2: Ceramic Ring and Bio ball

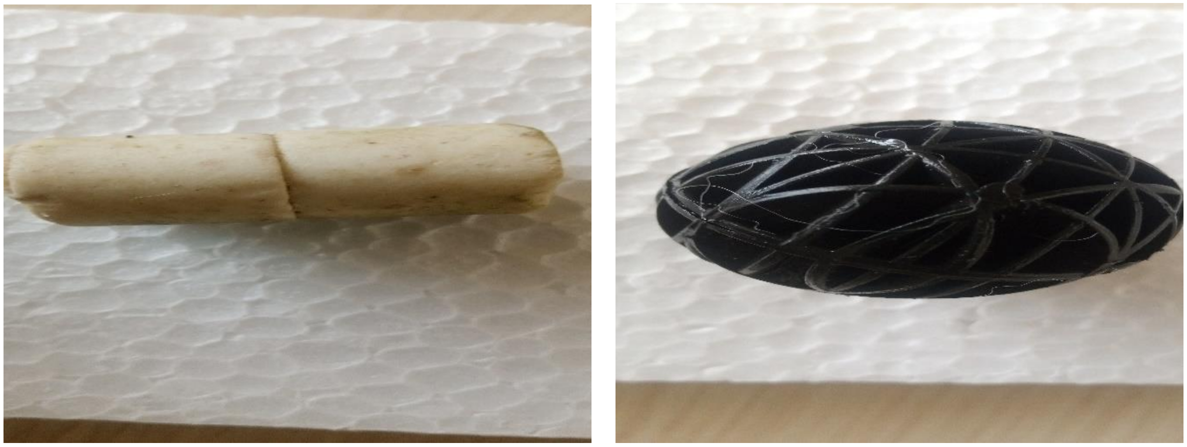


Table 1: Water – Parameters of fish tank

Weeks	T(^{O}C)	EC(ms/cm)	TDS(mg/l)	OD(ppm)	pH
1	26.2± 0.84	0.7± 0.071	490±49.49	5.4±0.894	6.56±0.166
2	26.6±0.548	0.6±0.054	450±27.38	6.4±0.55	6.61 ±0.074
3	26.4±0.55	0.66±0.054	450±27.78	6.4± 0.55	6.73 ± 0.133
4	26.4±0.55	0.66±0.054	450±27.38	6.4±0.55	6.81±0.111

Table 2: Water- Parameters of bio filtrate

Weeks	T(^{O}C)	EC(ms/cm)	TDS(mg/l)	OD(ppm)	pH
1	26.8± 0.45	0.7± 0.071	490±49.49	5.8±0.45	6.80±0.090
2	26.6±0.55	0.72±0.044	504±31.30	6.4±0.54	6.61±0.101
3	26.6±0.55	0.68±0.045	476±31.78	6.4± 0.55	6.78±0.083
4	26.6±0.55	0.66±0.054	462±62.61	6.4±0.55	6.79±0.083

Table 3: Water parameters for Holding tank 1

Weeks	T(^{O}C)	EC(ms/cm)	TDS(mg/l)	OD(ppm)	pH
1	26.8± 0.45	0.68±0.04	476±31.30	6.4±0.55	6.80±0.09
2	26.6±0.55	0.72±0.04	504±31.30	6.2±0.84	6.66±0.15
3	26.4±0.55	0.74±0.05	518±38.34	6.6±0.55	6.76±0.11
4	26.6±0.55	0.76±0.05	532±38.34	6.8±0.45	6.65±0.11

Table 3: Water parameters for Holding tank 2

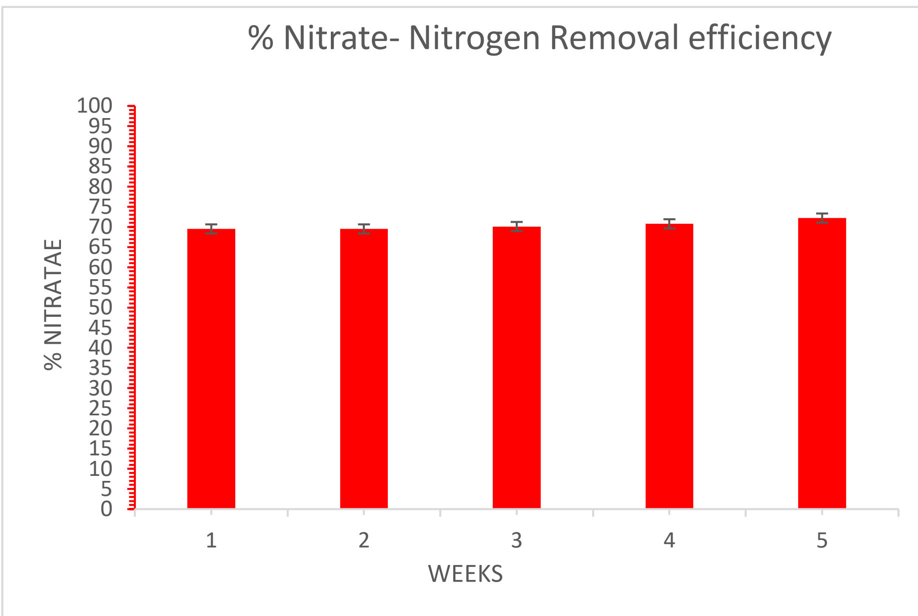
weeks	T(^{O}C)	EC(ms/cm)	TDS(mg/l)	OD(ppm)	pH
1	26.8± 0.45	0.66±0.05	469±38.34	5.8±0.45	6.20±0.09
2	26.6±0.55	0.62±0.04	434±31.30	5.6±0.55	6.17±0.06

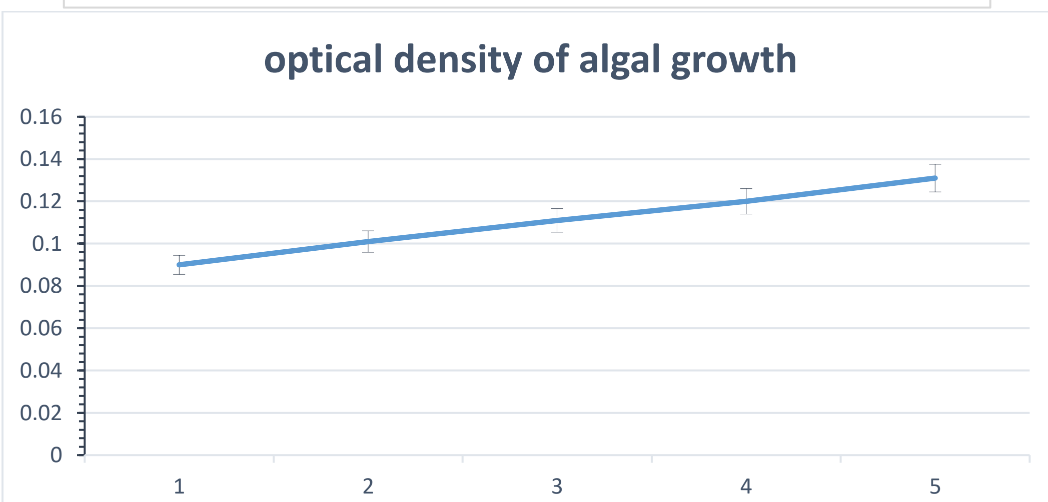
3	**26.4±0.55**	**0.62±0.04**	**434±31.30**	**5.4±0.55**	**6.16±0.05**
4	**26.6±0.55**	**0.6±0.07**	**420±49.50**	**5.0±0.71**	**6.14±0.08**

Table 4: BOD removal efficiency

Aquaculture effluent (Holding tank 1) (mg/l)	BOD Removal Across the beds(mg/l)	% BOD Removal Efficiency
14.66	**4.6**	**68.62**
15.7	**3.5**	**77.7**

Fig 2: Algal growth curve in fish tank





Discussion

The mechanical filter and bio sponge filter trapped all the uneaten fish feed when combined together. Considering the average nitrate concentrations of 2.8122 mg/l ± 0.131 in the first week of the experiment, 3.712 mg/l ± 0.308 in the second week, and 3.902 mg/l ±0.371 in the third week of the experiment in the bio filter, the bio ball used shows a good holding of beneficial bacteria for de-nitrification of the fish effluent in the biofilter tank. The primary function of bacterial communities in aquaponics is to convert food waste and fish faeces into macro- and micronutrients that plants may absorb.(Krastanova et al., 2022) , biofilters increase aeration through air exchange after each dewatering and provide consistent dispersion of nutrient-rich water throughout the filtering media during the flood cycle (Diver, n.d.) . From the results seen, the increase in nitrate concentration each week indicates that the biofilter functions very well. The bio ball and the ceramic rings have a good ability to hold beneficial bacteria in the biofilter.

However, water parameters such temperature, pH, and oxygen demand (OD) directly affect aquaponics systems in order to promote the nitrifying bacteria's economic growth as well as the growth of plants, fish, and algae. The weekly change of pH, oxygen demand, temperature, and EC all have physical and chemical effects in the design of aquaponics and also on waste water management.

The weekly change of pH, oxygen demand, temperature, and EC all have physical and chemical effects in the design of aquaponics and also on waste water management. Table 1 indicated the average parameters of the fish tank at a design flow rate (**Q_F**) of 3300 ml/min.Table 2 shows the water parameters of the bio filtrate, which is coming from the fish tank as effluent. The effluent was fed to the reactor from holding tank 1 (H_1) at a flow rate of 2400 ml/min. pH in the holding tank 1 was 6.80±0.09 at the first week of the experiment and 6.65±0.11 at the fourth week considering (*Goddek et al)* reported pH of 6 to 6.5 was discovered to be ideal for most crops to promote nutrient uptake. From our experiment pH of the effluent was reduced after it was fast through the plant bed (reactor) and collected in holding tank2(H2) as shown in table 3, this results of pH, EC, TDS also indicates that the effluent was treated in the reactor by the plants. We design the reactor to have a low flowrate of 2400 ml/min from holding tank 1 so that there will be efficient nutrient uptake by the plants and waste water treatment, and also the design flowrate of the effluent from the fish tank to the biofilter and then to holding tank 1 is also maintained at 3250 ml/min with an HRT of 8 minutes and 33 seconds. Our results of the water parameters of the bio filter show that our designed bio filter was very effective at nitrification in the system. As reported monitoring the water's nitrite, and nitrate levels regularly is the only way to assess the effectiveness of the biofiltration process (Krastanova et al., 2022) , Each week, the nitrate concentration was monitored and the nitrogen removal efficiency across the plant beds was calculated. As shown in Fig. 1, the nitrate nitrogen removal efficiency in the first week of the experiment was 69.5%, and the removal efficiency increased each week. This shows that our designed reactor flow rate influenced the nitrate nitrogen removal efficiency across the plant beds.

The nitrate- nitrogen removal across the bed in the reactor by the plants is shown in fig 5, the highest removal was at the 5th weeks, at 1st week it was 69. 50 % Nitrate removal across the bed while at the 5th week the removal increases to 72.2% across the beds. Also, the plant beds show maximum efficiency in BOD removal, as shown in Table 4, When holding tank 1's effluent was sampled, the BOD level was 14.66 mg/l. BOD removal from the effluent across the beds was 4.6 mg/l, with a 68.62% removal efficiency, BOD was taken again in the 3rd week of the experiment, the BOD level of the effluent was increase to 15.7mg/l and the removal of BOD across the plant was 3.5mg/l with percentage removal efficiency of 77.7%. From the results it shows that the plant is capable of waste treatment, the design flow rate and the designed beds influenced the removal efficiency.

The presence of algal in the fish tank influences the waste water management, in our experiment we monitored the growth of algae in the fish tank and how it influences the water parameters in the fish tank, the pH in the fish tank as showing in table 1

Conclusion

More thorough research should be done to determine the benefits of having algae in an aquaponics system and how it can help the system. Future research projects might involve various combinations of crops and other products used in aquaculture that are of a greater quality and market worth. More study is required to further aquaponics technology, which helps create more sustainable food systems. This research should focus on the effective flowrate, stocking density and Hydraulic loading rate.

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