

THE EFFECTIVENESS OF AQUAPONIC COMPARED TO MODIFIED CONVENTIONAL AQUACULTURE FOR IMPROVED OF AMMONIA, NITRITE, AND NITRATE

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ABSTRACT

Indonesia is currently faced with a variety of problems, including relating to increasing food demand and prices, increasingly scarce clean water, and poverty. Therefore, the development of aquaponics technology has been carried out, which integrates aquaculture and hydroponics. This study was conducted to compare water quality (pH, temperature, ammonia, nitrite, and nitrate) produced from 2 different systems, namely aquaponic with modified conventional aquaculture systems. In an aquaponic system, water recirculation follows the steps: Water from a fish pond tank (FPT), flows to mechanical tanks-1(MT-1), biofilter tanks (BT), mechanical tanks-2 (MT-2), to hydroponic plants (HP), and finally back to FPT, and so on. While conventional aquaculture systems, water recirculation is only through FPT, MT, and BT. The results were obtained for aquaponic (ammonia 0.350-5.946 mg/L, nitrite 0.193-0.880 mg/L and nitrate 1.031-5.542 mg/L), and for modified conventional aquaculture systems (ammonia 0.350-9.353 mg/L, nitrite 0.114-0.880 mg/L and nitrate 0.949-1.031 mg/L). While the pH and temperature values for the two systems are the same, pH 7.18-8.9, and water temperature 26.7- 30.0°C. After the t-test, both showed a significant difference where the aquaponics system was better than the modified conventional aquaculture system because the aquaponic system was supported by the presence of MT-1, BT, MT-2, HP, and FPT, while the modified conventional aquaculture systems were only supported by MT, BT, and FPT.

Keywords: Aquaponic, Modified Conventional Aquaculture, Ammonia, Nitrite, Nitrate

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INTRODUCTION

Indonesia is one of the developing countries, some of the problems encountered are increasing food demand, rising food prices, scarcity of clean water, and poverty. Another obstacle is the reduction in agricultural land, along with the increase in the number of population increases, so that the increasing number of people such as the measuring series is not comparable to food needs. One of the technologies that are feasible to develop is aquaponics technology supported by biofilter so that optimal water quality is obtained.¹⁻²

Based on the results of the research that has been done, show that the application of biofiltration ponds can increase production, land use and can save water usage during fish maintenance, while aquaponics systems are an integration between hydroponic plants and aquatic aquaculture, and become one of the effective solutions for food supply during the land crisis began to occur.³ In aquaponic systems, waste products from a biofilter system will be used as a nutrient. Waste from aquaculture animals will be used as a nutrient for hydroponic plants. The use of wastewater from aquaponic animals will be filtered, so as to produce water that can be a nutrient for hydroponic plants. The process is carried out repeatedly which is known as the recirculation system. The aquaponics system has many advantages, namely saving land

use and water, being environmentally friendly, producing organic fertilizers for plants, producing food products that have good quality and high nutritional value and can improve the economy.⁴

Aquatic animal wastewater, sourced from fish feces and the rest of fish food that accumulates and contains a lot of ammonia (NH_3), so it is toxic to cultivated organisms and can inhibit fish growth.⁵ In aquaponic systems, ammonia from the waste products from aquatic animals will be converted by decomposing bacteria that live on culture walls, planting media and filter media. *Nitrosomonas* sp bacteria will convert ammonia (NH_3) to nitrite (NO_2^-) then nitrite (NO_2^-) is converted to nitrate (NO_3^-) with the bacteria *Nitrobacter* sp, and then the nitrate conversion results are organic fertilizers so that the results of the research that have been done showed that the application of biofiltration ponds was able to increase production, land use and be able to save water usage during fish maintenance, while aquaponics systems are an integration between hydroponic plants and aquatic aquaculture, and become one of the effective solutions for food supply when land crises begin.³ In aquaponic systems, waste products from a biofilter system will be used as a nutrient. Waste from aquaculture animals will be used as a nutrient for hydroponic plants. The use of wastewater from aquaponic animals will be filtered, so as to produce water that can be a nutrient for hydroponic plants. The process is carried out repeatedly which is known as the recirculation system. The aquaponics system has many advantages, namely saving land use and water, being environmentally friendly, producing organic fertilizers for plants, producing food products that have good quality and high nutritional value and can improve the economy.⁴

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Aquaponics technology is proven to be able to produce fish optimally on narrow land and limited water sources so that with the combination of these technologies it is expected that households can meet food for consumption and can increase their income. Furthermore, the use of aquaponic technology can save land and water use, it can also improve business efficiency through the utilization of nutrients from the rest of the feed and metabolism of fish and is one of the environmentally-friendly fish farming systems.⁸

The hydroponic plants used in the aquaponic system in this study are Pakcoy (*Brassica rapa* L), which is one of the leafy vegetables that have high nutritional value, relatively fast planting time, can grow in the highlands and lowlands and has high economic value⁹, using Rockwool planting media and nutrients for plants derived from nitrates from ammonia reshuffle on aquaponic systems.⁷⁻⁸

Aquatic animals are chosen by *Oreochromis niloticus*, because these aquatic fish have relatively fast growth, can tolerate poor water quality, have a high tolerance to high salinity, high water temperature, low dissolved oxygen, and high concentrations of ammonia, and *Oreochromis niloticus* is suitable for cultivation in the area tropical.^{7-8,10} This study was conducted to compare water quality in an aquaponic system with a modified conventional aquaculture system.

EXPERIMENTAL

Tools and Materials

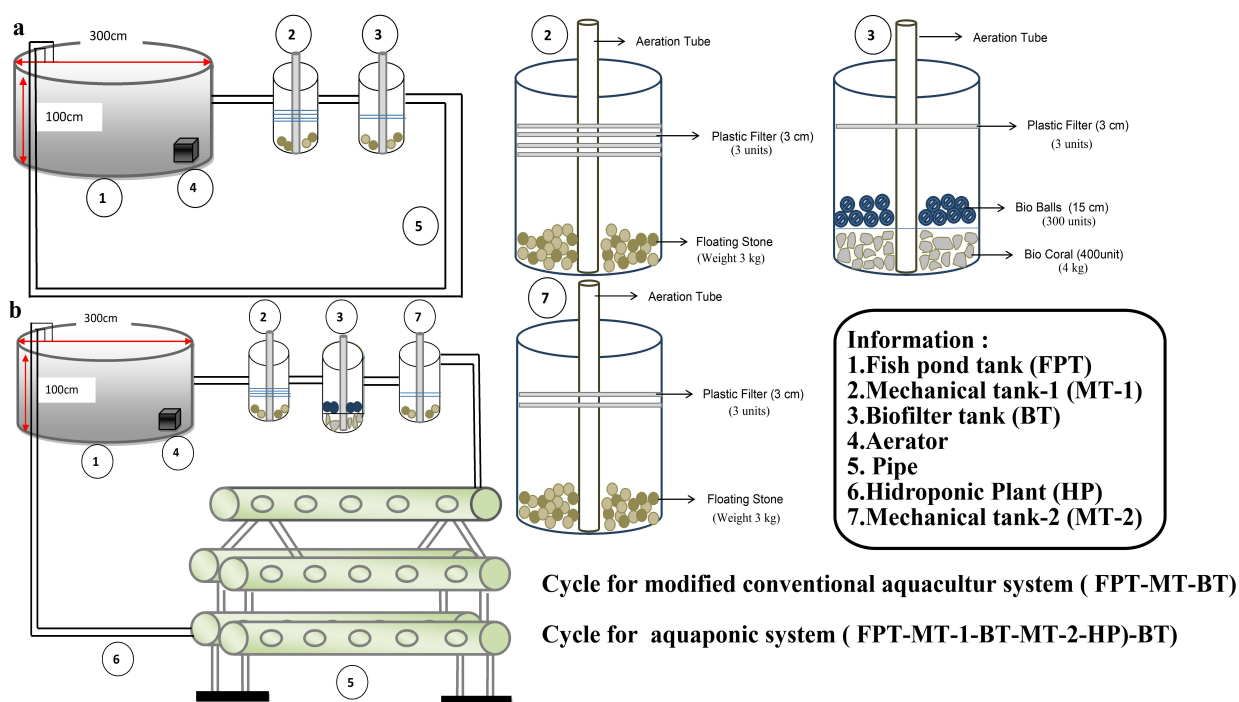
The tools used in this study were UV-Vis spectrophotometers (Shimadzu, UV-2700), analytical balance sheets, fish ponds, water pumps, water tanks, PVC pipes, net pots, aerators, and glassware commonly used in laboratories.

The materials used in this study were *tilapia*, fish feed, Pakcoy plants, planting media (Rockwool), water as much as 3 m³, and chemicals for analysis of water quality.

Series of Aquaponic And Modified Conventional Aquaculture Systems

The aquaponic and modified conventional aquaculture systems (Fig.-1) use a series of water streams consisting of FPT (diameter 300 cm and height 100 cm), MT (150 dm³), and BT (150 dm³). Especially for

modified conventional aquaculture systems are not equipped with hydroponic plants, and there is only 1 MT.



Research Procedure

Fig.-1: Modified Conventional Aquaculture Systems (a); Aquaponic Systems (b)

FPT is filled with fresh water as much as 3 m^3 , furthermore, water is given oxygen so that oxygen needs can be met, and during sampling, aeration is turned off. The stocked fish is *Oreochromis niloticus*, the size of length $\pm 3\text{-}5 \text{ cm}$, weight $\pm 4 \text{ g/piece}$ using a stocking density of $500 \text{ fish}/3 \text{ m}^3$ of water.

Before the fish are stocked into fish ponds, acclimatization is carried out with the aim that the fish are not stressed, and die. The fish feed (pellet) used was Prima Feed PF 1000 mixed with *Nitrosomonas bacteria* and given to fish at a dose of 2 kg of fish feed per 50 mL opak pferia.

The composition of MT consists of plastic filters (thick 3 cm , 3 units), and floating stone (as much as 3 kg), used to filter fish food that is not eaten, fish feces and other impurities, before entering BT. Furthermore, BT composition is a plastic filter (3 cm thick, 3 units), bio ball (300 units), biocoral (4 kg), which functions as a bacterial growth medium. Then flow to MT-2, to HP, and return to FPT again, and water recirculation begins again and continuously.

Preparation of Planting Media

The planting media used is Rockwool with a size of $40 \times 30 \text{ cm}$, then cut into $1 \times 1 \text{ cm}$ to facilitate the transfer of seedlings from the seedling media into the netpot. Netpot functions as a medium to support plants so that plant stems can stand firmly, netpots are associated with the flannel cloth which functions as an absorbent of water that passes through the system, so that the water can be stored in the planting media, and nutrients in the water can be absorbed by plants. Pakcoy plant seeds are sown for 2 weeks before being transferred to the hydroponic circuit. The number of Pakcoy plant seeds in the hydroponic sequence is 40 seeds .

Data Analysis

This study was conducted for 40 days , namely days $0, 10, 20,$ and 40 . Water quality parameters measured in aquaponic systems and modified conventional aquaculture systems: temperature ($^{\circ}\text{C}$), pH, ammonia

(mg/L), nitrite (mg/L), and nitrate (mg/L). The limit of optimal tolerance allowed for plant, fish and bacteria is probably not the same (Table-1), compromising water quality is needed (Table-2).¹¹ Furthermore, water quality data from both systems are compared using the t-test.

Table-1: Water Quality Tolerance For Fish, Hydroponic Plants and Nitrifying Bacteria

Organism type	Temp (°C)	pH	Ammonia (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)
Fish	22-32	6-8.5	< 3	< 1	< 400
Plants	16-30	5.5-7.5	< 30	< 1	-
Bacteria	14-34	6-8.5	< 3	< 1	-

Table-2: The Ideal Parameter For Aquaponics As A Compromise Between the Three Organisms

Plants	Temp (°C)	pH	Ammonia (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)
Bacteria	18-30	6-7	< 1	< 1	5-150

In aquaponic systems, water samples are taken from FPT, MT-1, BT, HP, and MT-2, whereas in the modified conventional aquaculture system, water samples were taken from FPT, MT, and BT.

RESULTS AND DISCUSSION

Analysis of Ammonia

Ammonia can affect water quality if the amount has exceeded the permissible threshold. The source of ammonia in aquaculture is waste food that is not eaten, feces, and dead organisms, and are toxic. Therefore, the toxic waste must be converted so it is not dangerous for the survival and growth of fish.^{7,12} The results of the studies that have been conducted, the ammonia content in the aquaponics and modified conventional aquaculture systems can be seen in Fig.-2.

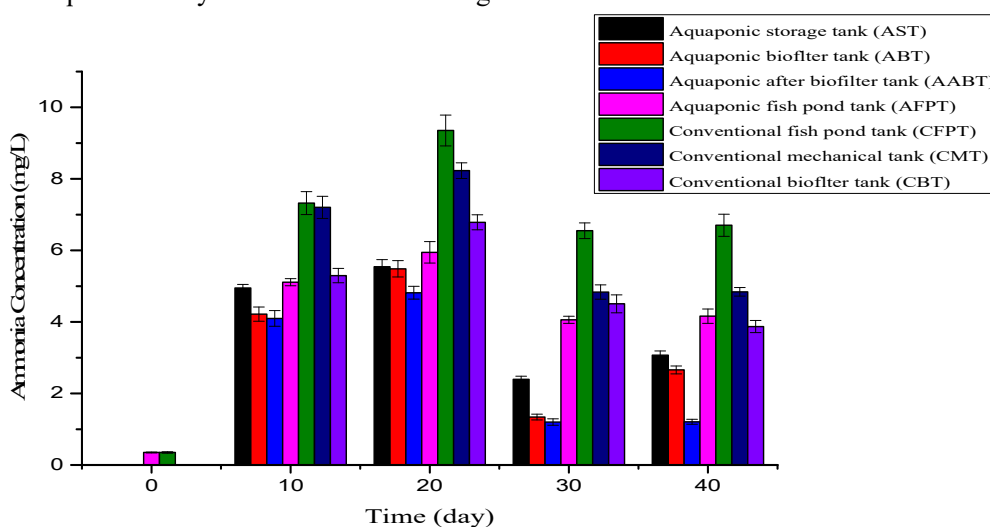


Fig.-2: Ammonia Concentration (mg/L) in Aquaponic and Modified Conventional Aquaculture

Based on Fig.-2, the ammonia content in the 0 the day is 0.350 mg/L. The sample on day 0 is a water source that will be used in a series of aquaponic and modified conventional aquaculture systems. On day 0, low ammonia levels were obtained, because the process of the aquaponics and the conventional aquaculture system had not yet begun.

In the aquaponic system, the concentration of ammonia on the 10th day in the FPT was 5.111 mg/L, MT-1 was 4.950 mg/L, BT was 4.218 mg/L, MT-2 was 4.098 mg/L, and the HP was 3.763 mg/L. Compared with ammonia levels on day 0 with the 10th day there was an increase because on the 10th day, the aquaponics system was already operating even though it was not optimal. Ammonia levels in FPT are higher because of the results of fish metabolism and fish food leftovers in fish ponds, which are the main

sources of ammonia.¹² In the MT-1, there is a slight decrease in ammonia levels because there is a filter in the MT-1, so there is a quite different decrease in the BT due to the presence of nitrifying bacteria. On the 20th day, there was an increase in ammonia levels in each tank. This is because nitrifying bacteria contained in the tank have not worked optimally and the rate of growth of fish, resulting in more metabolism than the previous day.

On the 30th day, the concentration of ammonia in the tank decreased. In FPT, ammonia levels were 4.060 mg/L, MT-1 2.394 mg/L, BT 1.341 mg/L, MT-2 1.202 mg/L, and HP was 0.176 mg/L. In general, the concentration of ammonia on the 30th day decreased from the 20th day. This is because the nitrification process has worked optimally. In the BT, MT-2 and HP, there was a significant decrease from the previous day, due to the presence of bacteria that had been converted into nitrate in the tank, so that the ammonia content was smaller.

Ammonia concentration on the 40th day was not significantly increased in FPT was 4.161 mg/L, MT-1 was 3.069, BT was 2.659 mg/L, MT-2 was 1.208 mg/L, and HP was 1.183 mg/L. Ammonia levels on day 40 increased compared to 30 days, which is directly proportional to the increase in pH and temperature. If the pH value and temperature increase, the ammonia content will also increase.¹³ The high ammonia level in water is accompanied by a reduction in water dissolved oxygen (DO). This is because nitrifying bacteria are aerobic bacteria that require oxygen in the nitrification process. If the oxygen content in the water is a little it will disrupt the course of the nitrification process. As a result, nitrifying bacteria cannot work optimally in converting ammonia to nitrate, so that the content of ammonia in the water increases. In accordance with the research conducted¹⁴, if the dissolved oxygen content in water is low, the ammonia level in the water will increase.

Based on Figure 2, there is a significant difference between the concentration of ammonia in a modified conventional aquaculture system with aquaponics system. Overall the ammonia content in a modified conventional aquaculture system (1.10-1.5 mg/L) is higher than that of aquaponic system (1.00-1.15 mg/L). This is because in a modified conventional aquaculture system without using hydroponic circuits. Hydroponic plants utilize the nitrate content that has been converted from ammonia, by making it a nutrient for plants, which in the end, flows clean water to the fish pond.

In accordance with the study¹⁵, ammonia levels in the modified conventional aquaculture system were higher than those of the aquaponic system. This is accompanied by a higher average number of fish deaths in a modified conventional aquaculture system. Based on study⁷, one of the factors that influence the concentration of ammonia is the ratio of the number of fish and plants. In conventional systems, there are no hydroponic plants, so that the ammonia content is higher than the aquaponic system. Overall, ammonia values from both systems have exceeded the allowed compromise threshold, yaitu < 1 mg/L¹⁶, presumably, because food that is not eaten is sunk at the base of FPT, and the *Nitrobacter* and *Nitrosomonas* bacteria have not functioned optimally in converting ammonia to nitrite and nitrate.

Analysis of Nitrite

Nitrites are inorganic nitrogen compounds. In fish farming, the content of nitrite in water is dangerous for the growth of fish and plants if it exceeds the limit of 0.02 mg/L. The results of the research on nitrite content in aquaponic system and modified conventional aquaculture system can be seen in Fig.-3.

In the aquaponics system (Fig.-3), the nitrite content was 0.193 mg/L on day 0 and has exceeded the concentration limit allowed for tilapia cultivation. On the 10th day, the nitrite concentration of each tank experienced a relatively large increase. Nitrite concentration on the 20th day also experienced a significant increase from the previous day. This increase in nitrite concentration increases with the concentration of ammonia in the water. However, on the 30th day, the nitrite concentration decreased. This is because, on the 30th day, it shows that the system is working optimally, which converts ammonia to nitrite.

On the 40th day, ammonia content was compared to 30 days, nitrite concentration in FPT was 0.329 mg/L, MT-1 was 0.316 mg/L, BT was 0.294 mg/L, MT-2 was 0.232 mg/L and HP was 0.213 mg/L. Based on the final results of nitrite concentration until the 40th day, it is known that the nitrite content is still below the threshold of the compromise of the three organisms (fish, plants, and bacteria) < 1 mg/L.¹⁶

The nitrite concentration in the modified conventional aquaculture system as a whole is higher than the aquaponics system (Fig.-3). Nitrite concentration on the 10th day on FPT was 0.710 mg/L, MT was 0.729

mg/L, and BT was 0.515 mg/L. On the 20th day, the nitrite concentration increased compared to the 10th day. But on the 30th-day nitrite concentration decreased, nitrite levels in FPT were 0.336 mg/L, MT was 0.152 mg/L, and BT was 0.143 mg/L. Nitrite concentration decreases because nitrite has been converted to nitrate. On the 40th day, the concentration of nitrite increased again, due to the increased ammonia content.

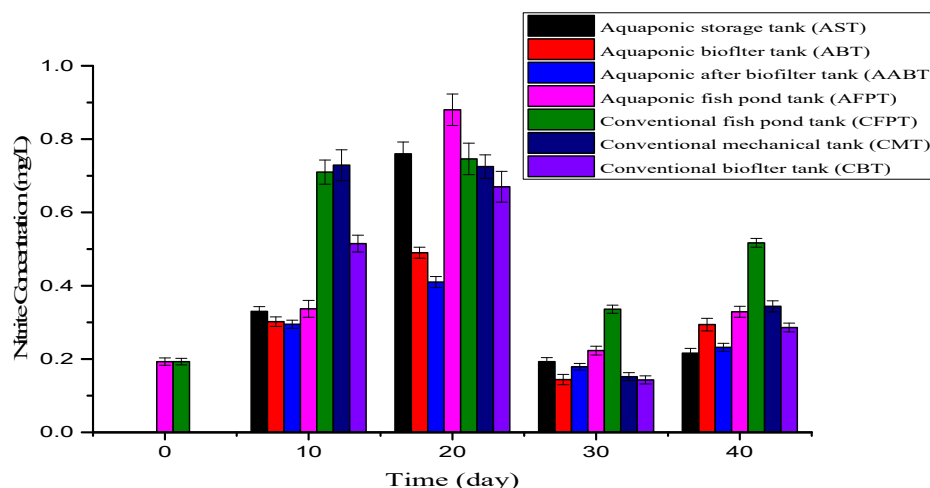


Fig.-3: Nitrite Concentration (mg/L) in Aquaponic and Modified Conventional Aquaculture

Based on Fig.-3, nitrite concentration in the modified conventional aquaculture system is higher than the aquaponics system, it is assumed that the oxygen content in the modified conventional aquaculture system is lower than the aquaponics system, so that the nitrite content in modified conventional aquaculture system accumulates more in the water than the aquaponic system.

Nitrite compounds cannot be used by plants as nutrients, so they must be broken down into nitrates with the assist of *Nitrosomanas* sp bacteria that need oxygen in the process.⁶ Excess nitrite content in water will have an effect on organisms in these waters because excessive nitrite compounds can reduce the ability of blood in organisms to bind oxygen, hemoglobin will react more strongly with nitrite compounds, which cause disruption of organism growth to cause death.¹⁵

Based on the results of studies that have been conducted, the nitrite values of the two systems are still below the allowed compromise tolerance limit, which is <1 mg/L¹⁶ indicating that *Nitrosococcus* bacteria are able to convert nitrite to nitrate optimally.

Analysis of Nitrate

Nitrate compounds are the final products of the nitrification process which are to some extent not harmful to fish growth and can be useful for plant growth as nutrients.¹⁷ The following is an observation of the nitrate content of the FPT, MT-1, BT, MT-2, HP found in Fig.-4.

Fig.-4, in the aquaponic system, the nitrate content on day 0 was 1.031 mg/L. Then there was an increase in nitrate concentration in the following days. The maximum nitrate concentration was obtained on the 30th day, which is the nitrate content in the FPT was 5.542 mg/L, MT-1 was 5.405 mg/L, BT was 5.050 mg/L, MT-2 was 4.275 mg/L, and HP was 4.149 mg/L. The high nitrate concentration obtained is because on the 30th day the nitrification process works optimally. This result is comparable to the small ammonia concentration on the 30th day, indicating that ammonia has been completely converted to nitrate. On the 40th day, there was a decrease in the level of nitrate in each tank from the previous day, it is estimated that the number of bacteria is reduced so that the bacteria cannot work optimally to meet the need for nitrates.

Fig.-4, nitrate concentrations in modified conventional aquaculture systems were overall lower than those in aquaponic systems. Nitrate concentration on the 10th day was obtained FPT 0.248 mg/L, MT was 0.433 mg/L, and BT was 0.167 mg/L. On the 20th day, there was an increase in nitrate concentration and

reached maximum concentration on the 30th day. Nitrate concentration on 30th day FPT was 0.949 mg/L, MT was 0.821 mg/L, and BT was 0.716 mg/L. The nitrate concentration increases to its maximum are due to the nitrification process, which is the bacteria *Nitrobacter* sp which converts nitrite to nitrate. On the 40th day, there was a decrease in nitrate concentration, a concentration of FPT was 0.836 mg/L, MT was 0.587 mg/L, and BT was 0.256 mg/L.

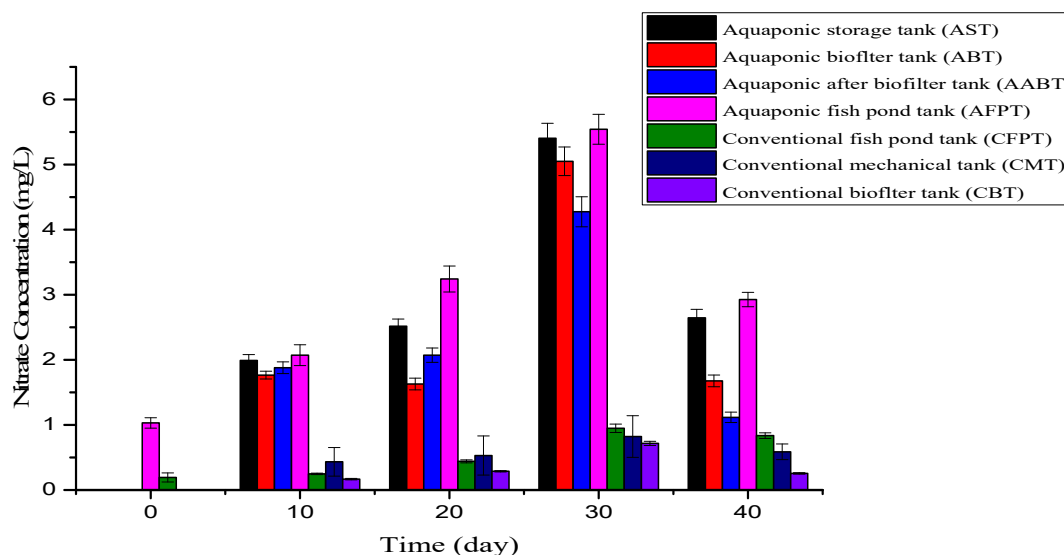


Fig.-4: Nitrate Concentration (mg/L) in Aquaponic and Modified Conventional Aquaculture

In general, the nitrate content obtained in a modified conventional aquaculture system is smaller than aquaponic system. This difference is caused by the modified conventional aquaculture system that nitrate compounds cannot be utilized maximally because there are no plants that will absorb nitrates. The low concentration of nitrate in a modified conventional aquaculture system is proportional to the low level of dissolved oxygen in the water. Decomposition of nitrite into nitrate by the bacteria *Nitrobacter* sp requires oxygen if the oxygen needed is not enough it will cause the nitrification process to not go well so that a small nitrate concentration is obtained.

Maximum nitrate concentration shows that the bacteria *Nitrobacter* sp that converts nitrite to nitrate works well so that plants can absorb nitrates well for growth. This is indicated by the maximum growth of Pakcoy plants on the 30th day of the aquaponic system. On the 40th day, the aquaponic system found nitrate concentrations to decrease, this was seen in the leaves of the Pakcoy plant becoming yellowish. Nitrate compounds are useful nitrogen compounds for plants, with reduced nitrate content, nutrients in plants are also reduced.

In the process of photosynthesis, plants generally need nitrogen which contains chlorophyll and sunlight which make green plants. Good nitrogen absorption by plants will increase growth because it affects the length of plant life, vegetative growth of plants can provide dyes to plants, and others.¹³ Based on study¹⁸, Pakcoy plants can absorb nitrate content better than spinach plants, lettuce and red spinach. The end result of the nitrification process is nitrate, which does not harm the plant if it does not exceed the limit. Based on the results of studies that have been carried out, the nitrate concentration in both systems is still below the concentration of compromise that is permitted, namely 50-150 mg/L.¹⁴ Therefore, it is necessary to create optimal conditions for the organisms of fish, plants, and bacteria so that nitrate needs can be met.

Analysis of pH

In a recirculation system, one of the important things is pH, because it functions as a balance between water, fish, and microbes.¹⁸ The observation of pH is directly measured at the sampling location, the results can be seen in Fig.-5.

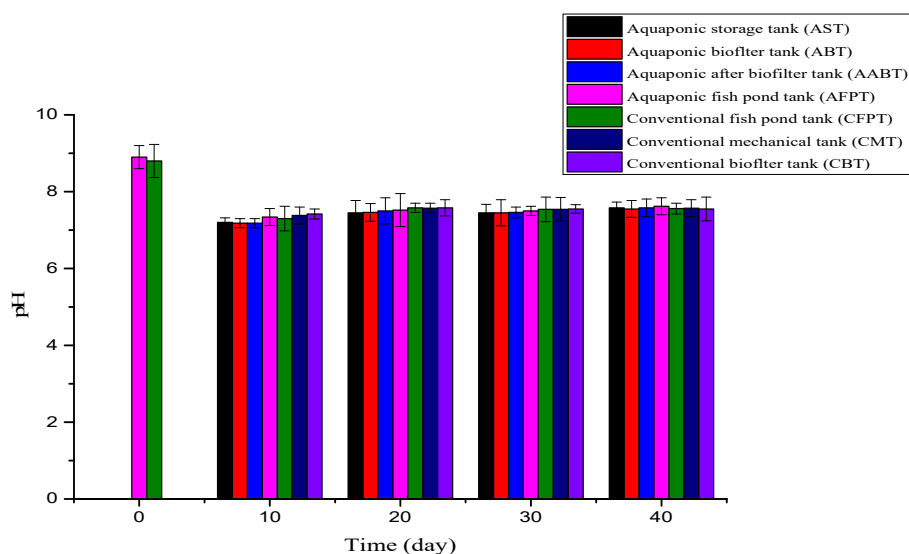


Fig.- 5: pH in Aquaponic and Modified Conventional Aquaculture System

Based on the observations obtained, the pH obtained at each sampling point in both aquaponic systems and modified conventional aquaculture systems meets with compromise water quality standards namely 6-7.¹¹

On aquaponic and modified conventional aquaculture systems on the 0th day, the pH values of water were 8.9 and 8.8 respectively. Then, the aquaponic system decreased on the 10th day, in the FPT was 7.34, MT-1 was 7.20, BT was 7.18, MT-2 was 7.18, and HP was 7.18. The pH in modified conventional aquaculture systems has decreased, namely at FPT was 7.30, MT was 7.38 and BT was 7.42. The pH value observed in the following days fluctuated and there was no significant difference with the pH value of the 20th day at each sampling point. Overall, the pH value obtained in a modified conventional aquaculture system is higher than aquaponic system.

The difference in pH values in the aquaponic system and modified conventional aquaculture systems will affect the content of ammonia in water. A high pH value in water is an indication of pollution of ammonia (NH_3) which is more dangerous for organisms compared to ammonium (NH_4^+) from the total amount of total ammonia nitrogen in the water. If the water pH value exceeds 7 then ammonium (NH_4^+) will not be ionized and will react with OH^- forming ammonia (NH_3) which is toxic and dangerous for fish. However, if the pH value of the water is less or equal to 7 then ammonium (NH_4^+) will be ionized.^{13,18} Therefore pH compromises fish, plants and bacteria tend to be slightly acidic 6-7.

pH values in modified conventional aquaculture systems were higher than for aquaponic systems, causes higher ammonia content in modified conventional aquaculture systems. Aquatic organisms, in general, can grow and develop at a neutral pH or 7. If the pH of the water is too low or too high it will disrupt the condition of the growth of the organism to cause death. *Tilapia* is one of the freshwater fish that can grow well in the water pH range 6.5-9.

Influence of Temperature

The value of water temperature obtained in the study ranged from 26.7-30.0°C. Measurement of water temperature is carried out directly at the sampling point, the water temperature value at each point does not have a significant difference, as can be seen in Fig.-6.

Figure-6, on day 0 the temperature of both systems was obtained 26.3 °C. Then, there was a temperature increase on the 10th day, the water temperature on the aquaponic system in the FPT was 28.4°C, MT-1 was 28.4°C, BT was 28.4 °C, MT-2 was 28.3°C, and HP was 28.2 °C. Likewise on the 10th day in the modified conventional aquaculture system in the FPT was 28.5°C, MT was 29.4°C and BT was 29.3°C. On the 30th and 40th day the water temperature values experienced small fluctuations at each sampling point.

The influence of weather conditions affects the temperature that causes the difference at each point. The increase in temperature on the 20th day is proportional to the decrease in oxygen levels in the water because if the water temperature increases it will increase the consumption of oxygen in the water for each organism.¹⁸ Reduced oxygen levels in the water will affect the activity of bacteria that require oxygen in the nitrification process, causing an increase in the content of ammonia in water. The activity and behavior of fish are influenced by the temperature if the temperature is too low or too high will cause competition between fish to obtain oxygen. Based on the results of the study¹⁹, the water temperature will affect the specific level of fish growth and the conversion ratio of eating fish.

The results obtained the water temperature in the aquaponic system and the modified conventional aquaculture system meets with the compromised water quality allowed 18-30°C¹¹, and feasible for the development of both systems.

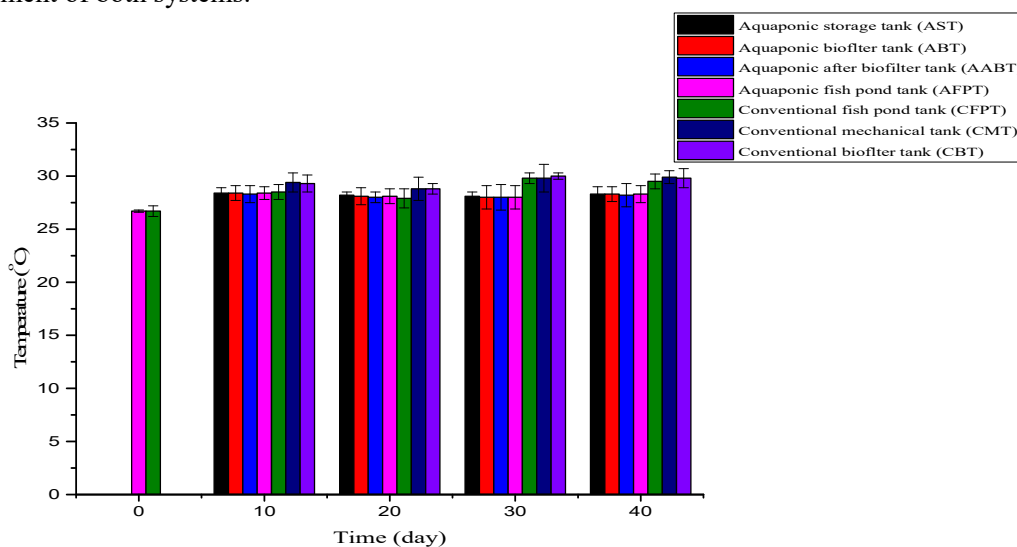


Fig.-6: Temperature (°C) in Aquaponic and Modified Conventional Aquaculture System

CONCLUSION

It can be concluded that aquaponic system and modified conventional aquaculture system showed a significant difference where the aquaponic system was better than the modified conventional aquaculture system because the aquaponic system was supported by the presence of MT-1, BT, MT-2, HP, and FPT, while the modified conventional aquaculture systems were only supported by MT, BT, and FPT.

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