Dynamics and fluctuations of ammonia, nitrite and nitrate in the utilization of tilapia cultivation waste in Aquaponics-NFT (nutrient film technique) based on biofloc

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Abstract. In an aquaponic system that integrates fish and plants, a recirculating aquaculture system (RAS) is used to circulate 90-99% water continuously. Fish waste is used for plant nutrition and reduces waste disposal in the environment. One of the functions of biofloc technology is to improve water quality. Several water quality parameters influence each other and do not stand alone. In the study of aquaponics, nutrient film technique (NFT) based on biofloc consisted of a fish pond tank (FPT), mechanical filter tank (MFT), biological filter tank (BFT), storage tank (ST), and hydroponic plant circuit (HPC). The results of the study show that the concentration of water quality parameters is always dynamic and fluctuates, namely: ammonia, from 0.4525 to 9.2625 mg L^{-1}; nitrite, from 0.1050 to 0.2238 mg L^{-1}; and nitrate, from 0.6226 to 9.7975 mg L^{-1}). In general, the concentrations of nitrite and nitrate were still within the permissible threshold interval, except for the ammonia concentration, which is very dynamic and fluctuates in a wide interval. The application of biofloc technology (BT) in aquaponics has contributed to technology for improving water quality, increasing fish survival, and fish and plant production.
Key Words: aquaponics, biofloc, dynamics, fluctuation, nutrients, RAS.

Introduction. In an aquaponic system that integrates fish and plants (Deswati et al 2018, 2019, 2020a, b), plants obtain nutrients mainly from fish feed waste (Roosta & Hamidpour 2013; Cerozi & Fitzsimmons 2017; Wongkiew et al 2017; Deswati et al 2021a, b, c, d), because fish can only absorb 20-30% of nutrients from fish feed, while the rest is released into the waters in the form of ammonia and organic protein (Avnimelech 2006). Fish waste is in the form of dissolved or suspended solids resulting from the excretion of fish through gills, feces, and from uneaten food residue, usually containing high concentrations of nitrogen and phosphorus (Roosta & Hamidpour 2013; Cerozi & Fitzsimmons 2017). Roosta & Hamidpour (2013) concluded that 80-90% of ammonia nitrogen excreted by fish is a nitrogen source for plants. Furthermore, macro and micro nutrients needed by plants are channeled into hydroponic components through the nitrification and mineralization processes (Rakocy et al 2006).

To reduce the negative impact of feed on the environment, it can be done by choosing materials of low trophic level (for example, proteins and lipids from phytoplankton rather than from fish), and effective feed digestion functions (Martins et al 2010), and the use of biofloc technology (BF) (Deswati et al 2020a, b, 2021a, b, c, d).

Biofloc is a heterogeneous macro aggregate of planktonic material in the water column, which is a consortium of floc-forming bacteria, diatoms, filamentous microalgae, micro and macro invertebrates, protozoa, feces and uneaten feed. Biofloc forms the basis of the food chain in aquatic ecosystems by converting them into single cell proteins (SCP). Therefore, bioflocs are responsible for early nutrient cycling processes in aquatic ecosystems (Avnimelech 2007; Avnimelech & Kochba 2009; Deswati et al 2020c, 2022a, b, c, 2023).

BT works based on the process of treating wastewater from fish feed. In intensive fish farming, high nutrient input causes the microbial community to increase rapidly. Only a small part of the nitrogen and carbon in the feed can be used for growth and metabolism of aquatic organisms. The average release of organic carbon, nitrogen, and phosphorus in feed by shrimp and fish was 13, 29, and 16%, respectively in the study of Avnimelech & Ritvo (2003). The remainder enters the aquaculture system either as inedible feed or as metabolic waste. If the rate of carbon and nitrogen in solution is manipulated, ammonium and other nitrogen components will be consumed by bacteria in mass production (Schneider et al 2006). Mass production of these microbes can be used in situ by farmed animals or collected and processed in feed contents (Hargreaves 2013; Deswati et al 2023).

BT is based on the principle of recycling nutrients by maintaining a higher C/N ratio (> 15) to stimulate the growth of heterotrophic bacteria (Avnimelech 1999). A higher C/N ratio is maintained when more carbon sources (starch, wheat bran, straw, sugar cane, cellulose, molasses, cassava and others) are sprayed onto the surface of the pond water with continuous aeration. Under favorable BT conditions, up to 0.5 g heterotrophic bacterial biomass/g carbon substrate can be produced (Eding et al 2006). With the information that 1 g of carbon produces 0.5 g of bacteria, farmers can estimate the number of flocs in the culture system. The biofloc process stimulates the natural growth of macro-organism aggregates that can increase nitrification in water (Deswati et al 2022a).

BT is a modern and adaptive technology that works based on the mass production of microorganisms in situ. Microorganisms are used to: (1) improve water quality (Emerenciano et al 2017; Deswati et al 2021a, b, c, 2022a, b, 2023); (2) increase the feasibility of cultivation by reducing feed conversion ratio (FCR) and feed costs (Deswati et al 2023); (3) biosecurity (Defoirdt et al 2004); and (4) absorption of green-house gases (Manan et al 2016). The four biological functions of microorganisms in this BT are high fish production factors, profitability and environmental protection.

The advantages of using BT are: (1) BT does not require water exchange, so it requires less water input, minimizes the entry of animal pathogens through water and increases biosecurity in fish farming (Wasielesky et al 2006); (2) BT allows fish to be reared with higher stocking densities (Crab et al 2010, 2012); (3) biofloc can be used as feed for cultured fish so as to produce lower FCR and reduce feed costs (Ekasari et al 2010; Megahed 2010); (4) bioflocs increase fish survival because bacteria in biofloc act as immunostimulants for aquatic animals (Krummenauer et al 2011; Pérez-Fuentes et al 2016); (5) biofloc enhances immunity-related genes (Browdy et al 2014); (6) biofloc is used as a nutrient that is available at any time, so that it can accelerate the weight of the fish that are kept (Avnimelech 2007; Deswati et al 2023); (7) bacteria in biofloc produce polyhydroxybutyrate (PHB) which is beneficial in digestion and fatty acid metabolism (de Schryver et al 2012); (8) heterotrophic bacteria are responsible for converting nitrogen compounds released by fish and used for growth, eliminating the toxicity of ammonia and nitrite (Azim & Little 2008; Nootong et al 2011) and utilizing toxic nitrogenous materials as substrates to improve water quality (Burford et al 2004; Hari et al 2004; Wasielesky et al 2006).

In this study, Nile tilapia (*Oreochromis niloticus*) was used because it is omnivorous, grows fast, FCR is low, and is tolerant to fluctuations of water quality (Deswati et al 2018, 2019, 2020a, b, 2021a, b, c, d). Furthermore, for intensive tilapia maintenance, it is necessary to have good water quality management for fast growth and high survival (Effendi et al 2015).

The use of aquatic plants in aquaponics as part of a biological filter system has proven to be effective in improving water quality. Aquatic plants are proven to be able to absorb toxic substances in the form of ammonia and nitrite (Deswati et al 2018, 2020c). Types of vegetables that can be grown with an aquaponic system are plants that have tolerance to wide changes in water quality, such as Samhong mustard (*Brassica juncea* L.) (Deswati et al 2018, 2022c, d). Therefore, in this study, Samhong mustard was used as a hydroponic plant.

In a previous study (Deswati et al 2020c), a comparison of water quality parameters (ammonia, nitrite, and nitrate) has been carried out between aquaponic systems without biofloc and conventional fish farming systems. In general, water quality in aquaponic systems without biofloc proved to be better than conventional fish farming systems. Furthermore, in the present study, Aquaponics-NFT (nutrient film technique) based on biofloc was used to improve water quality and to study the fluctuations and dynamics of water quality.

Material and Method

Research time and location. The research was carried out from December 2021 to March 2022. The manufacture of aquaponic systems was carried out at Blasta Rumah Hydroponics, Ulak Karang. Sample analysis was carried out at the Applied Analytical Laboratory of the Department of Chemistry, Andalas University, Basic and Central Laboratory of Andalas University.

Instruments. The instruments used in this study were atomic absorption spectrophotometer (AAS) (Perkin Elmer AA-100), UV-Vis spectrophotometer (PANanalytical), FTIR (Unican Mattsoon Mod 7000 FTIR), DO meter, analytical balance (Kern & Sohn GmbH), fish pond tank (FPT, 1 unit), mechanical filter tank (MFT, 1 unit), biological filter tank (BFT, 1 unit), storage tank (ST, 1 unit), hydroponic plant circuit (HPC), water pumps, aerators, PVC pipes, and glass equipment commonly used in laboratories.

Materials. The materials used in this study were fish feed, 35 stems of Samhong mustard seeds, planting medium (rockwool), 1000 individuals of Nile tilapia, biolacto bacteria (100 g), banana (3 pieces), pineapple (1 piece), egg (3 grains), vitamin C (3 grains), vitamin B complex (3 grains), tape yeast (1 item), baker's yeast (1 sachet), sugar (1.25 kg), Yakult (which is one of the probiotics used in the development of biofloc) (7 bottles), molasses (75 mL), doubly distilled water, and chemicals for sample analysis.

Biofloc system bacterial culture. The ingredients for the bacterial culture of the biofloc system are biolacto bacteria, banana, pineapple, egg, vitamin C, vitamin B complex, tape yeast, baker's yeast, sugar, Yakult, molasses. Then provided a plastic gallon which already contains 19 liters of water as a container for bacterial breeding. Some of the ingredients that have been provided are mashed using a blender. The mashed ingredients are pineapple, banana, vitamin C, vitamin B complex, and tape yeast. Then into the plastic gallon we put the egg yolks, granulated sugar, biolacto bacteria and the ingredients that have been mashed. After that, the aerator is installed and closed tightly until no air enters. Bacterial culture was carried out for one week. After one week, if the bacterial culture is successful, it will smell like the slight fermented yeast and will have a fresh yellow color (Deswati et al 2020c, 2021c, d, 2022a, b, c, 2023).

The stages of giving biofloc nutrition per week. Dolomite lime (50 g) was weighed, dissolved in 50 mL of water, put into FPT, allowed to stand for 30 minutes. Then put 250 g of salt, wait 30 minutes, add a mixture of molasses and water that has been boiled and cooled as much as 75 mL. Then put bacteria that have been cultured using different variations (150; 200; 250; 300; 350; and 400 mL) every week.

Preparation of aquaponic system. The Aquaponic-NFT system (Figure 1) consists of 4 compartments, namely: FPT with a length, width and height of 119, 100, 74 cm, respectively. The MFT, BFT and ST volumes are the same (110 dm^3). The aquaponics system is equipped with HPC consisting of 45 stems of Samhong mustard and rockwool growing media. The FPT was filled with 1000 individuals of Nile tilapia with 2-3 cm length and 0.6500 g weight. The aquaponics system is designed to be equipped with a recirculating aquaculture system (RAS), the water is supplied with a pump system, starting from FPT, MFT, BFT, ST, HPC and back to FPT.

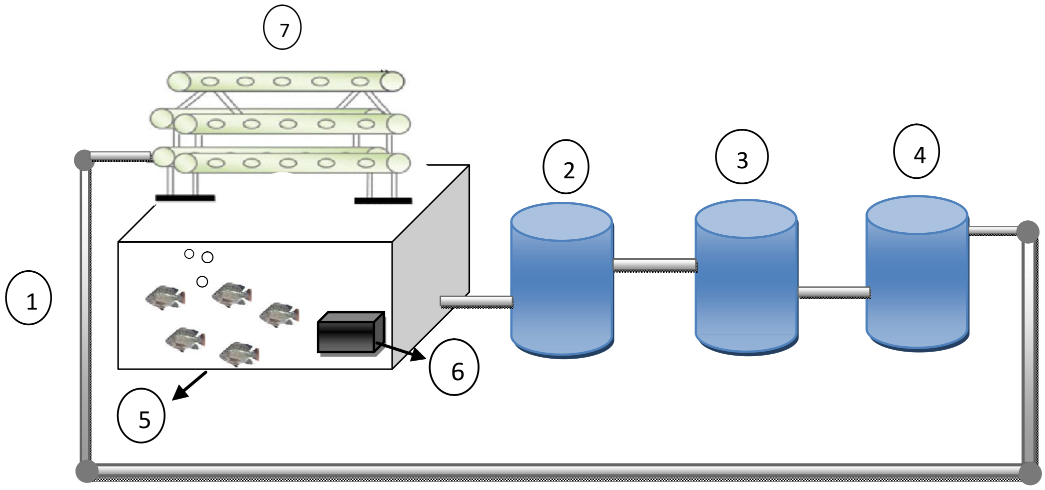

Figure 1. Aquaponic-NFT system: 1. pipe into FPT; 2. MFT (mechanical filter tank); 3. BFT (biological filter tank); 4. ST (storage tank); 5. FPT (fish pond tank); 6. aerator; 7. HPC (hydroponic plant circuit).

The MFT was filled with 110 dm^3 of water, and a plastic filter was inserted in order to filter the sediment. The BFT was equipped with an aerator used to supply oxygen needs for microorganisms. Bio-ball and bio-coral were added to the BFT, functioning as a substrate for bacteria that will convert ammonia to nitrite and nitrate.

Aquaponic system analysis. In this study, water quality parameters were analyzed, namely: ammonia, nitrite, and nitrate. Water sampling from FPT, BFT and HPC was carried out 5 times for 42 days (days 0, 7, 14, 35, and 42).

Tilapia fish were put into FPT after water sampling on day 0. The aquaponic system was left to operate without plants for 1 week so that the plants get sufficient nutrients for their growth. The measurements of Nile tilapia growth were carried out on day 0 and day 42, while plant measurements were carried out on day 14 and day 42. During the study, fish were fed 2% of their body weight twice a day, in the morning and evening.

Data analysis. Sampling of water from FPT, BFT, HPC was carried out to obtain data on water quality parameters such as: ammonia, nitrite and nitrate. Then the water quality data obtained were compared with data obtained in other studies (Table 1).

Table 1

The optimal water quality parameters for fish, plants and bacteria

Parameter	*Values*				*References*
	Plant	*Fish*	*Bacteria*	*Optimum*	
pHdeleted	6-6.5	7-9	5-9	6.8-7	Goddek et al (2015)
	-	-	-	6.5	Schmautz et al (2017)
	5.5-7.5	-	6-8.5	6-7	Somerville et al (2014)
	-	7-8	-	-	Graber & Junge (2009)
	-	-	7-8	-	Al-Hafedh et al (2008)
	-	-	-	7.2	Wortman (2015)
Temperature (°C)	16-30	22-32	14-34	18 - 30	Somerville et al (2014)
DO (mg L^{-1})	4-8	-	-	> 5	Somerville et al (2014)
	> 3	-	-	-	Trejo-Tellez & Gomez-Merino (2012)
	-	> 6	-	-	Graber & Junge (2009)
	-	-	> 2	-	Masser et al (1992)

Ammonia (mg L^{-1})	< 30	-	< 3	< 1	Somerville et al (2014); Sallenave (2016)
Nitrite (mg L^{-1})	< 1	-	<1	< 1	Somerville et al (2014)
	-	< 0.2	-	-	Graber & Junge (2009)
Nitrate (mg L^{-1})	-	-	-	5-150	Somerville et al (2014); Sallenave (2016)
	-	-	-	120	Schmautz et al (2017)
	-	<150	-	-	Graber & Junge (2009)

Results and Discussion

Ammonia concentration analysis. The concentration of ammonia in the test sample can be seen in Figure 2. Based on Figure 2, the concentration of ammonia during the study tends to increase, presumably because the ammonia reduction process through the assimilation process by plants, as well as through the nitrification process by bacteria has not functioned optimally. According to van Kessel et al (2015), ammonia reduction can be carried out in several ways, including through biological processes such as plant assimilation, decomposition by bacteria, nitrification, denitrification, and aeration processes. The nitrification process is influenced by several factors, including the substrate and dissolved oxygen (DO), organic matter, temperature, pH, alkalinity, salinity, and turbulence (Crab et al 2007). The level of ammonia toxicity in aquatic organisms will increase with increasing pH and water temperature and when there is a decrease in DO content in fish culture media.

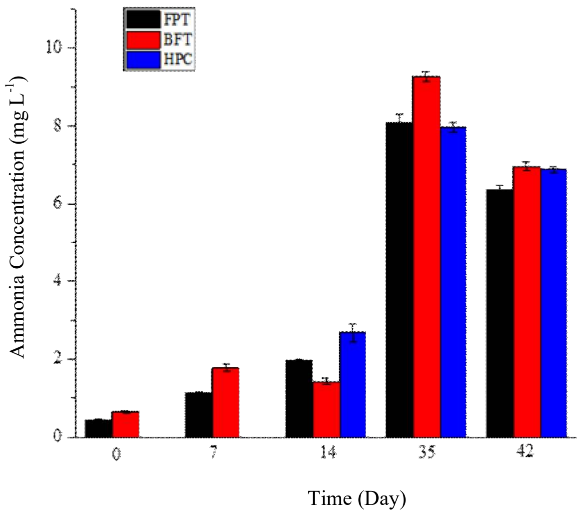

Figure 2. Ammonia concentration (mg L^{-1}) in different time observations (days).

On day 0, the concentration of ammonia in FPT and BFT was 0.4525 and 0.6415 mg L^{-1}, respectively. This small ammonia concentration is because the activity in the aquaponics system has not yet started. On days 0-7, the ammonia concentration was low, presumably due to the process of utilizing ammonia directly by plants through the phytoremediation process by Samhong mustard and optimal BT performance (Palao et al 2020).

On days 7-14, the concentration of ammonia increased in FPT and BFT respectively 1.1409 and 1.774 mg L^{-1}, it was suspected that the aquaponic system had started to function and fish had started to grow.

On the 14th day, the ammonia concentration increased again, presumably due to the remains of fish metabolism (faeces) and uneaten fish feed so that they were suspended at the bottom of the pond. Ammonia concentrations in FPT, BFT and HPC were 1.9784, respectively; 1.4389 and 2.6778 mg L^{-1}.

On the 35th day, the concentration of ammonia increased rapidly in FPT, BFT and HPC respectively 8.0917; 9.2625 and 7.9708 mg L^{-1}, presumably due to a lack of bacterial population that converts inorganic nitrogen into microbial mass (Deswati et al 2023).

On the 42nd day the concentration of ammonia decreased in FPT, BFT and HPC respectively 6.3481; 6.9666 and 6.8778 mg L^{-1}. The decrease in the concentration of ammonia originating from fish waste and fish feed residue was because the bacteria in the biofloc and nitrification consortium were able to convert ammonia into nitrites and nitrates effectively (Goddek et al 2015). This condition indicates that the biofloc system is running well. Ammonia concentrations in FPT, BFT and HPC were in the interval 0.4525-9.2625 mg L^{-1}. Then the results of this study were compared with water quality in other studies (Somerville et al 2014; Sallenave 2016) (Table 1), which was < 1 mg L^{-1}, meaning that the ammonia concentration was very dynamic, fluctuating and tended to exceed the maximum allowable threshold. This was presumably due to the increasing concentration of ammonia from uneaten feed and fish metabolic waste. The accumulation of organic and inorganic materials causes the formation of toxic compounds for fish. The nitrification process is needed to convert harmful ammonia into nitrate through nitrite compounds as an intermediate. In this condition, the appetite and growth of tilapia usually decrease at concentrations of ammonia greater than 0.08 mg L^{-1}, so that the resistance of tilapia decreases. However, the study results showed contradictory results, namely high tilapia survival (> 95%), presumably because during the study other water quality parameters were optimal (pH 6.3-7.1; DO 6.2-7.8 mg L^{-1}; temperature 26.2-28.3^{o}C). This finding is in accordance with the opinions of Goddek et al (2015), Schmautz et al (2017), Somerville et al (2014), Wortman (2015) that optimal pH is 6-7.2; Somerville et al (2014) that optimal DO is > 5 mg L^{-1}; and Somerville et al (2014) that optimal temperature is 18-30^{o}C.

According to Deswati et al (2020c), high concentrations of ammonia cause damage to the nervous system and gills of fish, resulting in a weakened immune system. Other signs and symptoms include red streaks on the body, lethargy, and panting on the surface of the water. At higher ammonia concentrations, the effect is mass fish mortality, but a decrease in ammonia over a long period causes fish stress, increasing disturbance and more fish mortality. Furthermore, Bhatnagar & Devi (2013) emphasized that ammonia values > 0.1 mg L^{-1} tend to cause gill damage, damage on mucus-producing membranes, sub-lethal effects such as decreased fish growth, increased FCR, decreased disease resistance, osmoregulation imbalance and kidney failure. In general, if fish are poisoned by ammonia, fish movements slow down or fish pant on the surface of the water.

The toxicity of non-ionized ammonia for short-term exposure is usually in the range of 0.6-2.0 mg L^{-1}, and sublethal effects may occur at 0.1-0.3 mg L^{-1} (Bhatnagar & Devi 2013). The maximum limit of ammonia concentration for aquatic organisms is 0.1 mg L^{-1} (Santhosh & Singh 2007). According to OATA (2008) ammonia levels < 0.02 mg L^{-1} are considered safe. Stone & Thomforde (2004) stated the desired range as total NH_3-N is 0-2 mg L^{-1} and un-ionized NH_3-N is 0 mg L^{-1}, an acceptable range as total NH_3-N < 4 mg L^{-1} and non-ionized NH_3-N: < 0.4 mg L^{-1} (Stone & Thomforde 2004). Bhatnagar et al (2004) suggested that 0.01-0.5 mg L^{-1} of ammonia is required for shrimp; ammonia > 0.4 mg L^{-1} is lethal to many fish and shrimp species; ammonia 0.05-0.4 mg L^{-1} has a sublethal effect and ammonia < 0.05 mg L^{-1} is safe for many species of tropical fish and shrimp. Bhatnagar & Singh (2010) recommend an appropriate level of ammonia (< 0.2 mg L^{-1}) for brackish water aquaculture.

Based on the present study the values of ammonia (0.4525-9.2625 mg L^{-1}) have exceeded the optimal water quality for integrated aquaculture of fish, plants and bacteria (< 1 mg L^{-1}) (Somerville et al 2014; Sallenave 2016; Table 1). Furthermore, Graber & Junge (2009) stated that for cultured fish ammonia is toxic at concentrations > 0.2 mg L^{-1}, while for plants ammonia will be deadly if the concentration is > 30 mg L^{-1}) (Somerville et al 2014; Sallenave 2016). Nitrite is the result of oxidation in the first stage of the nitrification process. Nitrite is not used by plants but is decomposed with the help of oxygen by *Nitrosomonas* bacteria and will be converted into nitrate when oxygen needs are met (Djokosetiyanto et al 2006), and the supply of oxygen is assisted by aeration (oxygenation); water mixing and water circulation in aquaponics is carried out using the RAS concept (Gjesteland 2013).

Analysis of nitrite concentration. The results of the analysis of the nitrite concentration in the test sample can be seen in Figure 3.

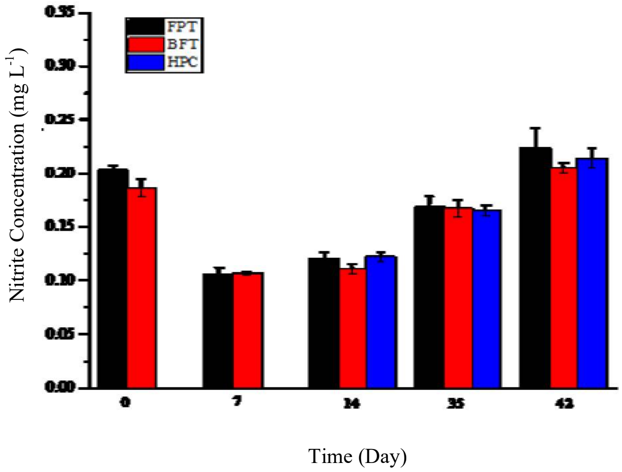

Figure 3. Nitrite concentration (mg L^{-1}) in different time observations (days).

Figure 3 shows that on day 0 the nitrite concentrations in FPT and BFT were 0.2031 and 0.1865 mg L^{-1}, respectively, presumably because the aquaponics system was still not functioning optimally.

On the 7th day, the nitrite concentration decreased in both FPT and BFT, respectively 0.1050 and 0.1061 mg L^{-1}, presumably because the nitrification process was functioning.

On day 14, nitrite concentrations increased in both FPT, BFT, and HPC, presumably due to metabolic waste and fish feed which is a source of ammonia that was converted into nitrite and nitrate effectively.

The concentration of nitrite in the three compartments ranged from 0.1050 to 0.2238 mg L^{-1}. Based on the results of this study compared with water quality in other studies (Somerville et al 2014; Sallenave 2016) (Table 1), the allowable threshold value for nitrite is < 1 mg L^{-1}. Stone & Thomforde (2004) suggested that the desired range of nitrite is 0-1 mg L^{-1} and the acceptable range of nitrite is less than 4 mg L^{-1}. Furthermore, Bhatnagar et al (2004) stated that nitrite concentration of 0.02-1.0 mg L^{-1} caused fish death, nitrite > 1.0 mg L^{-1} caused death of warm water fish and nitrite < 0.02 mg L^{-1} was acceptable. Santhosh & Singh (2007) recommend nitrite concentration in water < 0.5 mg L^{-1}. OATA (2008) recommends that the concentration of nitrite should be < 0.2 mg L^{-1} in fresh water and < 0.125 mg L^{-1} in seawater.

Overall, the concentration of nitrite in the aquaponic system is within the optimal allowable limit (Graber & Junge 2009; Sommerville et al 2014) (Table 1); it is suspected that the biofloc system has been able to improve water quality, mainly based on the ability of heterotrophic microorganisms to utilize organic and inorganic N contained in water so that the concentration of N in water will be lower (Carbajal-Hernández et al 2013).

Analysis of nitrate concentration. Nitrate is the end product of the nitrification process, and is needed by plants as a source of nutrients (Sommerville et al 2014). The results of the analysis of nitrate concentrations in the test samples can be seen in Figure 4.

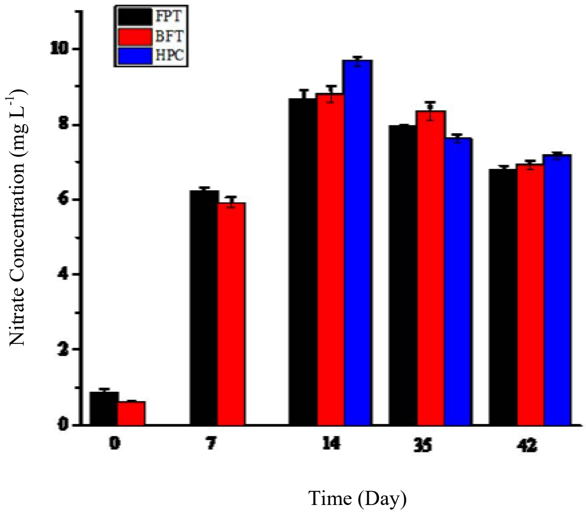

Figure 4. Nitrate concentration (mg L^{-1}) in different time observations (days).

Figure 4, on day 0 the nitrate concentrations in FPT and BFT were 0.8535 and 0.6226 mg L^{-1}, respectively, presumably because the aquaponic system cultivation activity had just started, so there was an influence from the treatment. On the 7th day, the nitrate concentration in the water increased, and then on the 14th day, the nitrate concentration increased rapidly/drastically. This can be explained that the increase in nitrate concentration due to the performance of bacteria on biofloc and nitrifying bacteria effectively converts from nitrite to nitrate, but plants are slow to utilize the nutrients produced by bacteria. On days 35–42, the concentration of nitrate in FPT, BFT and HPC decreased. This condition occurs because bacteria work effectively in reducing ammonia so that they can absorb nitrate well (Pratama et al 2017), in addition to the findings of Wahyuningsih et al (2016), that nitrate is needed by plants as a source of nutrition, and its presence is very influential on growth. If sufficient supply of nutrients is available, plant growth will be fast, otherwise if lack of nutrients growth will be slow and plants will become stunted.

Nitrate concentrations in FPT, BFT and HPC tend to be dynamic and fluctuate from 0.6226 to 9.7975 mg L^{-1}. Furthermore, the results of this study were compared with water quality in other studies (Somerville et al (2014), Sallenave (2016), Schmautz et al (2016) stated that the allowable threshold value for nitrate is 5-150 mg L^{-1}). According to Stone & Thomforde (2004), nitrate is relatively non-toxic to fish and does not harm fish health except at very high concentrations (above 90 mg L^{-1}). Santhosh & Singh (2007) recommend a favorable range of 0.1-4.0 mg L^{-1} in freshwater aquaculture. However, Santhosh & Singh (2007) and OATA (2008) recommend that the nitrate concentration in marine aquaculture should not exceed 100 mg L^{-1}. Overall, the nitrate content in aquaponic systems does not exceed the threshold range nitrate in water.

Growth of tilapia and Samhong mustard. On day 0, the total length and weight of the fish were 2-3 cm and 0.6500 g respectively, while on day 42 the the total length and weight were 6.1-7.0 cm and 4.6961 g respectively, with a survival rate of 95%. This can be explained by the supply of nutrients derived from fish feed pellets, as well as from flocs from biofloc with high nutrient content, which can reduce FCR (Ekasari et al 2010; Megahed 2010), accelerate growth (Avnimelech 2007, 2009) and increase survival (Krummenauer et al 2011; Pérez-Fuentes et al 2016).

Leaf length measurements on Samhong mustard were carried out on days 14, 35, and 42. The results showed that leaf length was directly proportional to planting time. In plants of biofloc-based aquaponic cultivation, there were no signs of nutrient deficiency such as slow growth, discoloration to yellow, white, and brown, or necrotic spots on the leaves of mustard.

Conclusions. The water quality parameters (ammonia, nitrite, and nitrate) in a biofloc-based aquaponic system are always dynamic and fluctuate. The concentration of nitrite (0.1050-0.2238 mg L^{-1}), and nitrate (0.6226-9.7975 mg L^{-1}) is still within the permissible threshold interval, except for the concentration of ammonia (0.4525-9.2625 mg L^{-1}). Several factors affect the concentration of ammonia: (1) the source of the pollutant comes from uneaten fish feed residue, fish metabolic waste, and the resulting waste has exceeded the carrying capacity of the aquaponic system; (2) the performance of bacteria in biofloc and nitrifying bacteria are not optimal in breaking down ammonia into nitrites.

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Conflict of interest. The authors declare that there is no conflict of interest.

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