Hydroton-biofloc-based aquaponics (hydroton-flocponics): towards good water quality and macro-micro nutrient

[1]Deswati, [1]Safni, [1]Latisha Putri Isara, [2]Hilfi Pardi

[1] Department of Chemistry, Faculty of Mathematics and Natural Science, Andalas University, Kampus Limau Manis, Padang, 25163 Indonesia; [2] Department of Chemistry Education, Faculty of Teacher Training and Education, Raja Ali Haji Maritime University, Senggarang, Tanjungpinang, Indonesia. Corresponding author: Deswati, deswati@sci.unand.ac.id; deswati_ua@yahoo.co.id

Abstract. This study investigated the usage of hydroton-flocponics, which combines biofloc-based aquaculture (tilapia, *Oreochromis niloticus*) with hydroponics (lettuce, *Lactuca sativa* L.) and has hydroton as a plant medium. The findings reveal the following parameters of water quality analysis: dissolved oxygen (DO) (6.1-7.06 mg L^{-1}), biological oxygen demand (BOD) (1.380-3.996 mg L^{-1}), chemical oxygen demand (COD) (4.248-15.552 mg L-1), phosphate (0.826-11.23 mg L-1), sulfate (24.62-41.94 mg L-1), potassium (1.92-15.66 mg L^{-1}), Ca (5.02-19.59 mg L^{-1}), Cu (0.0038–0.032 mg L^{-1}), Fe (0.0138-2.03 mg L^{-1}). The amounts of DO, BOD, COD, sulfate, Ca, K, and Cu, with the exception of phosphate and Zn, are generally within permitted quality criteria, while the legal levels for Fe have not been identified. Results also show that hydroton has the following features: (1) has a high porosity, which allows for smooth water circulation; (2) can keep plant roots oxidizing at all times; (3) is environmentally friendly and renewable; (4) is reusable; (5) is easy to use; and (6) hydroton is a good colony for microbial populations. Hydroton as a growing medium in a biofloc-based aquaponic system is recommended for the future since it can improve water quality and macro-micro nutrients.
Key Words: aquaculture, hydroponics, a biofloc-based aquaponic system.

Introduction. In recent years, population growth, food demand, and urbanization have intensified, resulting in a decrease in agricultural area and overfishing, particularly in coastal waters (Deswati et al., 2021a). To address the increased demand, environmentally friendly food production technology, like aquaponics, is necessary. Aquaponics is a hybrid of hydroponics and aquaculture that uses a recirculating aquaculture system (RAS) (Deswati et al., 2018, 2019, 2020abcde; Stathopoulou et al., 2018). Hydroponics, also known as soilless gardening, is a method of growing plants in a nutrient solution that contains all of the nutrients necessary for optimal plant growth, with or without the use of inert media such as gravel, vermiculite, Rockwool, peat moss, sawdust, coir dust, coconut fiber, and other similar materials (Connolly & Trebic, 2010; Bernstein, 2013; Hambrey Consulting, 2013). Microorganisms in aquaponics turn fish waste into nutrients that hydroponic plants can use in this setup (Medina et al., 2016; Nuwansi et al., 2016; Zou et al., 2016; Munguia-Fragozo et al., 2015). Aquaponic technology has evolved into a sustainable and environmentally friendly agricultural production system due to its integrated nature. Because of their ability to maintain water quality, minimize water use, provide healthy vegetable crops, and be pesticide-free, organic hydroponic vegetable products have been widely used by the public and are believed to improve health and immunity (Espinosa-Moya et al., 2016; Shete et al., 2016), organic hydroponic vegetable products have been widely used by the public, and are believed to improve health and immunity (Pratopo and Thoriq, 2021), especially in the face of covid 19.

In an aquaponics system, the concentration of organic compounds is formed by 70-80% of feed collecting in water and only 20-30% of feed being digested by fish, resulting in nutritional waste from uneaten feed residue (Faizulla et al., 2019; Deswati et al., 2020d).

Flocponics (biofloc-based aquaponic system) (Pinho et al., 2021) is a strategy for enhancing water quality that combines biofloc-based aquaculture with hydroponics. It works on the premise of recycling fish waste nutrients (Avnimelech, 2009; Kuhn et al., 2010). Adjusting the C/N ratio in the water, modifying the carbohydrate content of the feed, or bringing an additional carbon source to the water, which bacteria convert into nitrogen molecules useful to plants (nitrates and nitrites), all aid the establishment of heterotrophic microbiota in biofloc (Crab et al., 2012; Martinez et al., 2020). As a result, ammonia/nitrite concentrations can be kept low and non-toxic, and water changes can be avoided.

Biofloc technology (BFT) is a closed aquaculture system based on the microbial-loop idea, in which the growth of a specific microbial community in the fish and/or shrimp tanks is fostered, such as heterotrophic and nitrifying bacteria (Ebeling and Timmons, 2012; Rurangwa and Verdegem, 2015). Specialized microbial communities in biofloc-based culture allow for the intense and biosafe cultivation of aquatic organisms. The use of BFT systems has long been developed, and the technology is well-established, but BFT in aquaponics is still relatively new, and it is still done by trial and error. As a result, further research into topics like nutrient recycling and water quality is needed.

In a flocponics, the Fish Tank (FT), Mechanical Filter-01 (MF-01), Mechanical Filter-02 (MF-02), Biological Filter (BF), Storage Tank (ST), and Hydroponic Subsystem (HS), which is a series of recirculation systems with varied purposes, are all used (Deswati et al., 2021bc). In addition, hydroton (expanded clay) is provided as a medium for growing lettuce, enhancing the effectiveness of HS. Hydroton is significant because it can store nutrients, act as a plant buffer (Diver, 2006), is round in shape, has pores to collect water, helps plants retain nutrients, and is an ideal colony for microbial populations (Rosman et al., 2019).

Lettuce and tilapia were used as test organisms. Lettuce is commonly utilized in aquaponics systems and can be consumed alone or in combination with other meals (Zidni et al., 2017). Furthermore, lettuce plants are being utilized in phytoremediation to cleanse fish waste and absorb pollutants. By washing pollutants into harmless forms, they can be eliminated, inactivated, or immobilized (Hadiyanto and Christwardana, 2012). Lettuce is cultivated in an aquaponic system, which means it doesn't need inorganic fertilizers to flourish and instead feeds itself with feces and fish food waste (Pratopo and Thoriq, 2021). Monsees et al. (2019) confirmed that the lettuce generated is healthy and hygienic since lettuce leaves can produce phenolic and antioxidant compounds favorable to human health. Tilapia was chosen as the test animal because it is widely cultivated, has a high tolerance for changes in water quality, can survive for several hours at low dissolved oxygen (DO) concentrations, can survive at pH 5-10, and can thrive at pH 6-9, and can live for several hours at low DO concentrations.

Hydroton-flocponics (hydroton-biofloc-based aquaponics) is used in this study to increase water quality and macro-micro nutrients in aquaponic system with lettuce and tilapia. DO, biological oxygen demand (BOD), chemical oxygen demand (COD), and macro-micro nutrients (P, S, K, Ca, Cu, Fe, and Zn), as well as hydroton analyses, were all done on the water (concentration and composition, functional groups, and characterization to determine morphology and pore size).

Experimental

Tools. The following instruments were used in this study: AAS Spectrophotometer (Perkin Elmer AA-100), UV-Vis Spectrophotometer (PAN analytical), FTIR Spectrophotometer (Unican Mattson Mod 7000 FTIR), SEM-EDX (Hitachi S-3400N), XRF Spectrophotometer (PANanalytical Epsilon 3), DO meter, analytical balance (Shimadzu), Fish Tank (FT), Mechanical Filter-01 (MF-01), Mechanical Filter-02 (MF-02), Biological Filter (BF), Storage

Tank (ST), and the Hydroponic Subsystem (HS), water pumps, aerators, baskets, PVC pipes, and glassware commonly used in laboratories.

Materials. The following materials were used in this study: Tilapia, lettuce, fish feed (pellets), Rockwool, hydroton, plastic filter, bio balls, bio coral, biofloc material, and chemicals for sample analysis.

Biofloc system bacterial culture*.* The procedures of (Deswati et al., 2020b,c) were utilized to manufacture bacterial culture materials for the biofloc system and conduct bacterial culture experiments. The ingredients include bacteria (*Bioflacto* sp) (100 g), banana (150 g), pineapple (650 g), eggs (165 g), vitamin C (3 items), vitamin B complex (3 items), cassava fermentation (11.2 g), yeast (11 g), sugar granulate (1.25 kg), Yakult (455 mL), and molasses (75 mL). The bacteria culture container is a gallon with 19 liters of water already in it. Some of the prepared ingredients, such as pineapple, banana, vitamin C, vitamin B complex, and cassava yeast, were mashed in a blender. Egg yolk, sugar, refined ingredients, and *Biolacto bacteria* were also added. After that, the aerator was installed and shut tightly to prevent air from entering. Bacterial culture was carried out for two weeks, and active bacterial culture produced a slight fermented yeast odor.

Stages of giving biofloc nutrition per week. Dolomite lime, weighing up to 50 g, is dissolved in 50 mL of water, then poured into a fish pond, and left to sit for 30 minutes. After that, 250 g of salt were added to the pool, left for 30 minutes before adding a 75 mL mixture of molasses and previously heated and chilled water. Then, every week, put bacteria that have been cultured in different variations, such as 150 mL, 200 mL, 250 mL, 300 mL, 350 mL, and 400 mL.

Hydroton-flocponics system preparation. The hydroton-flocponics system consisted of an FT (1.20 x 1 x 0.80) m, MF-01, MF-02, BF, ST, each measuring 110 dm^3, and an HS filled with hydroton as a planting medium (Fig. 1). FT is swarming with 8-12 cm fish, with up to 200 fish every 0.80 m^3 of water. The MT-01 and MT-02 consists of a plastic filter (3 cm thick, 2 units), and serves to capture nutrients from the fish feed as well as dead biofloc. The BT is made up of bio balls and bio coral, which serve as a location for bacteria to live by attaching to the surface, as well as water with a 1:1 ratio of *Nitrosomonas* and *Nitrobacter* spp, and an aerator to provide oxygen. Hydrotons are utilized in the HS function to assist plants in retaining nutrients and absorbing water, allowing them to obtain the nutrients they require.

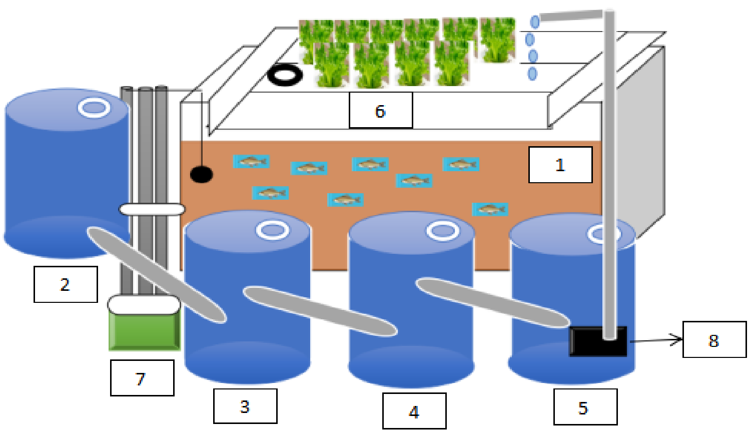


Fig. 1. Hydroton-flocponic system circuit
1.FT ; 2.MF-01 ; 3.MF-02; 4.BF; 5.ST ; 6.HS; 7. Aerators; 8. Pump
Source: authors elaboration

Mechanical filters (MT-01 and MT-02) filter water flowing from an FT. Water is pumped through the BT after particle removal, where it is biologically converted via two phases of bacterial nitrification. Water flows into the ST, then the HS, in the same order. The FT was refilled with water, and the procedure was carried out once more (Recirculating Aquaculture System, RAS). A water pump controls the flow of water, whereas an aerator controls the flow of oxygen. The aerator is used only by the FT (10 points) and BF (3 points).

Hydroton-flocponics system analysis. A water quality analysis is done first, which covers: (1) DO, COD, and BOD measurements, as well as (2) macro-micro components (P, S, K, Ca, Cu, Fe, and Zn). Because the hydroton particles are clay, analysis was carried out to: (1) determine the concentration and composition using X-Ray Fluorescence spectrophotometry, (2) determine the functional groups using FTIR, and (3) characterize the hydroton particles using Scanning Electron Microscopy (SEM) to determine the morphology and pore size.

Water samples were taken on FT, BF, and HS on days 0, 7, 14, 21, 28, and 35. A day-0 sample was taken after the hydroton-flocponics system was started. The micro-macro-nutrient components were evaluated on day 0 and day 35. Hydroton samples were gathered both before and after use (end of study).

Results and Discussion

DO concentration analysis. DO is required for the production of biofloc and is used in the plant respiration process. It produces energy that aids in the absorption of water and nutrients. In aquaponic systems, the concentration of DO can affect plant growth (Coada et al 2020),. Low DO levels in tilapia cause suboptimal growth as a result of nutritional inadequacy, which can result in fish death (Dabrowski et al., 2018; Manahan, 2017; Bhatnagar and Devi, 2013).

According to Fig. 2, the average DO concentration during the trial (days 0-35) was 6.1-7.06 mg L^{-1}. DO concentrations in FT, BT, and HS were 6.78 mg L^{-1}, 6.51 mg L^{-1}, and 6.62 mg L^{-1}, respectively. The DO concentration used in this hydroton-flocponics system met the quality standard of the permissible threshold (Government Regulation of the Republic of Indonesia Number 22 of 2021 class III), indicating that the water quality for freshwater fish farming and crop irrigation is > 3 mg L^{-1}.

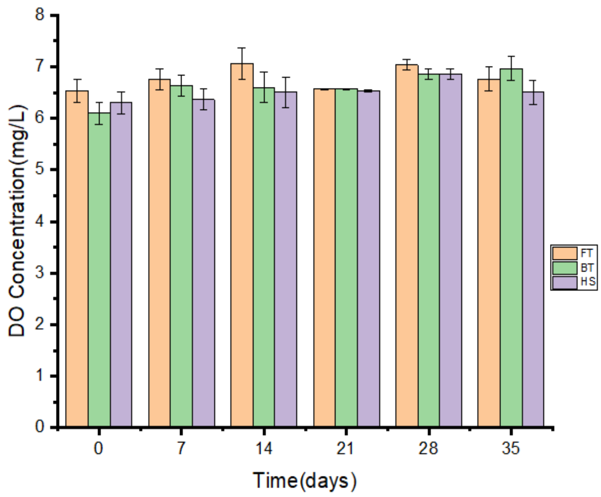


Fig. 2. Relationship of DO concentration (mg L^{-1}) with time variation (days) (Source: authors elaboration based on analyses results)

Biofloc was added to FT once a week to allow the bacteria in the biofloc to convert nutritional waste from fish waste and fish meal that the fish didn't eat into nitrite, which was then changed into nitrate, which was required for plant growth. The improved biofloc performance was thought to be due to the optimal DO 6.51 - 6.78 mg L^{-1}.

BOD concentration analysis. Microbes require a certain level of DO to digest organic matter in water, which is measured in BOD. Because there is a lot of organic matter in the water, a high BOD content is an indicator of poor water quality (Hlordzi et al., 2020).

According to Fig. 3, the average BOD concentration (day 0–35) was 1.380–3.996 mg L^{-1}. BOD concentrations in FT, BT, and HS were 2.614 mg L^{-1}, 2.735 mg L^{-1}, and 1.998 mg L^{-1}, respectively. A BOD of 6 mg L^{-1} is considered good water quality for freshwater fish cultivation and crop irrigation (Government Regulation No. 22 of 2021 class III). According to the average BOD content (day 0–35), the water utilized in the hydroton-flocponics system met the acceptable threshold quality standards for freshwater fish aquaculture and agricultural irrigation.

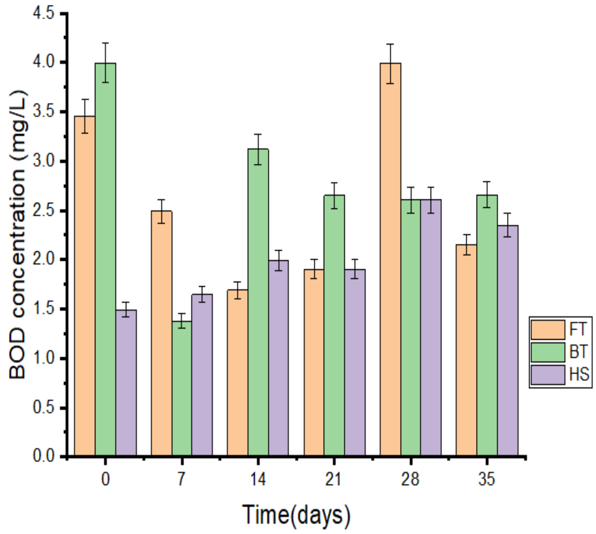


Fig. 3. Relationship of BOD concentration (mg L^{-1}) with time variation (days) (Source: authors elaboration based on analyses results)

In FT, the average BOD concentration (day-0) was 3.458 mg L^{-1}, then declined until day-14, then climbed again on day-21, reaching its peak concentration (3.990 mg L_{-1}) on day-28. Although the BOD value fluctuates every week, this ideal BOD concentration encourages nitrifying bacteria to work at their optimum.

The average BOD concentration in HS fluctuates, with the highest average BOD concentration of 3.996 mg L^{-1} on day 0. Plants are thought not to have absorbed inorganic materials, leaving a large amount of organic matter for bacteria to decompose (FAO, 2012). The increased BOD concentration indicates deterioration in water quality. Between days 21 and 35, however, there was no substantial difference, and plants were able to absorb more inorganic components in the water. This is due to the fact that the water used in freshwater fish farming and crop irrigation meets the required quality criteria.

COD concentration analysis. The amount of oxygen required to chemically oxidize organic and inorganic substances as well as particles in water is referred to as COD (Hlordzi et al., 2020; Deswati et al., 2020b; Ekasari et al., 2016). Because heterotrophic bacteria in the water require oxygen, the concentration of COD in a hydroton-flocponics system is controlled by the quantity of oxygen demand.

According to Fig. 4, the average COD concentration (days 0–35) was 4.248 – 15.552 mg L^{-1}. COD concentrations in FT, BT, and HS were 8.775 mg L^{-1}, 9.034 mg L^{-1}, and 8.979 mg L^{-1}, respectively. COD of 40 mg L^{-1} is considered good water quality for freshwater fish farming and crop irrigation (Government Regulation of the Republic of Indonesia No. 22 of 2021 class III). The COD concentration (day 0-35) demonstrates that the water utilized in this hydroton-flocponics system meets the acceptable threshold quality criteria for freshwater fish farming and agricultural irrigation.

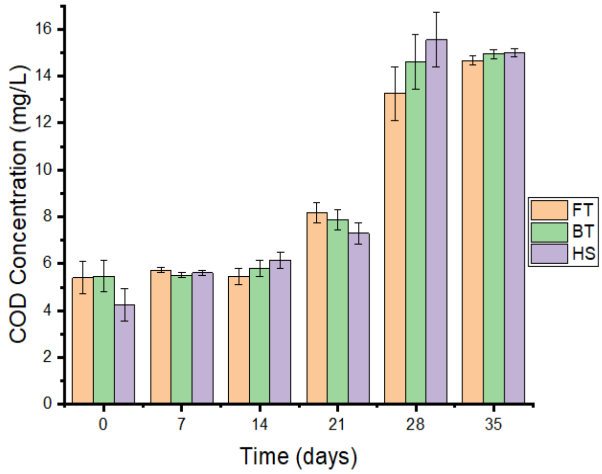


Fig. 4. Relationship of COD concentration (mg L^{-1}) with time variation (days)
(Source: authors elaboration based on analyses results)

The average COD concentration in the FT (day-0) was 5.400 mg L^{-1}, while the average COD concentration (days 14–28) increased, owing to the amount of organic matter deposited in the FT from feed and fish excrement. The COD concentration on FT on the 35th day had declined slightly as some of the organic waste had decomposed into inorganic components. The addition of nitrifying bacteria to BT converted organic molecules into inorganic ones.

Phosphate concentration analysis. Phosphorus in wastewater is categorized into three categories: phosphorus particles (which settle at the pond's bottom), suspended phosphorus (which is less dense than phosphorus particles), and dissolved phosphorus (which is soluble in water) (Sugiura, 2018; Jasmin et al., 2020). Some particulate phosphorus accumulates in MT-01 and MT-02, but dissolved phosphorus will remain and eventually be discharged into the environment (Jasmin et al., 2020; Sugiura, 2018).

According to Fig. 5, the average phosphate concentration in water is 0.826 -11.23 mg L^{-1}. (days 0-35). FT, BT, and HS had phosphorus values of 6.761 mg L^{-1}, 6.387 mg L^{-1}, and 6.192 mg L-1, respectively. For freshwater fish farming and crop irrigation, a total phosphate level of 1 mg L^{-1} is considered ideal (Government Regulation of the Republic of Indonesia Number 22 of 2021 class III). In FT, the average phosphate concentration (day-0) was 0.826 mg L-1, which is the maximum allowed. On days 7-35, however, the average phosphate concentration used surpassed the allowed quality standard for freshwater fish farming and agriculture irrigation.

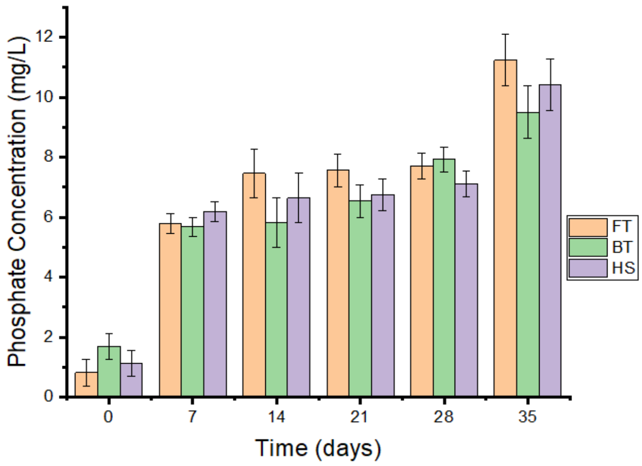


Fig. 5. Relationship of Phosphate concentration in water (mg L^{-1}) with time variation (days)
(Source: authors elaboration based on analyses results)

Plants require phosphorus concentration as a macronutrient to grow optimally. The average phosphate concentration on day 0 was 3.581 mg L^{-1}, while the average phosphate concentration on day 35 was 4.959 mg L^{-1}. Phosphate values did not affect lettuce plants, according to observations, even if the average value of phosphate had above the permitted threshold.

The element silica oxide (SiO_2) in the hydroton can cause a drop in phosphate because when it is exposed to water, it deoxidizes, releasing the element O from the Si element. The vacancy of O ions in Si causes Si to attract other ions until it reaches equilibrium. At this moment, O ions in phosphate (PO_4) are pulled and broken down by one silicate to produce SiO_2 and release two additional O ions in the form of free oxygen O_2 (Kushayadi et al., 2018). The chemical reaction of phosphate and hydroton can be seen by the following equation:

$SiO_2+H_2O \rightarrow Si +4O+H$ (initial deoxidation)

$Si +4O+H \rightarrow Si + 2H_2O+ 2O$

$Si + PO_4 \rightarrow SiO_2+ 2O+ P$ (P uptake by plants)

On FT, the average phosphate concentration in fish (day-0) was 0.673 mg L^{-1}, while it was 0.928 mg L^{-1} on day 35. The total phosphate content of good quality fish is 1 mg L^{-1}. (Government Regulation No. 22 of 2021 class III). The amount of phosphate consumed by tilapia is proportional to the body's requirements, and any excess phosphate is expelled in the form of feces and urine.

Sulfate concentration analysis. Sulfur, especially as a sulfate ion, is a crucial ingredient for plants, fish, and bacteria in hydroton-flocponics systems. Sulfur decomposes to sulfide and is oxidized to sulfate in aerobic circumstances.

According to Fig. 6, the average sulfate concentration in water from day 0 to 35 was 24.62-41.94 mg L^{-1}. Sulfate concentrations in FT, BT, and HS were 29.81 mg L^{-1}, 32.82 mg L^{-1}, and 34.96 mg L^{-1}, respectively. A sulfate level of 300 mg L^{-1} is considered good for freshwater fish farming and crop irrigation (Government Regulation No. 22 of 2021 class III). The average sulfate content in this study meets the required threshold quality standard value, allowing it to be used in hydroton-flocponics system production.

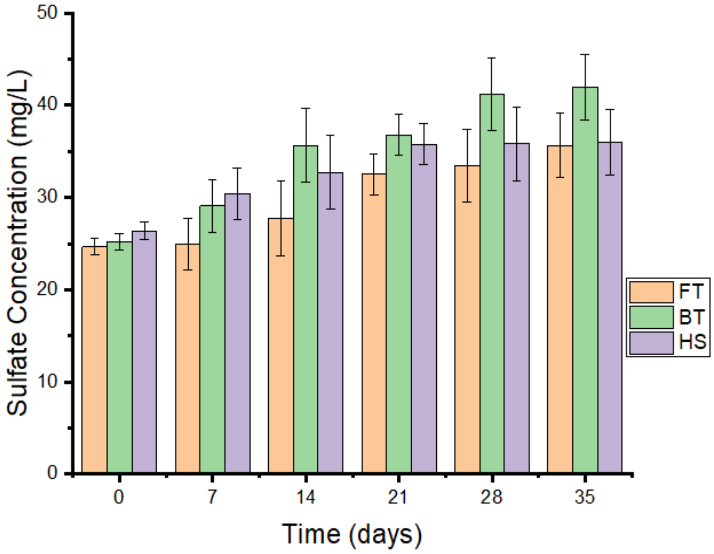


Fig. 6. Relationship of Sulfate concentration in water (mg L^{-1}) with time variation (days) (Source: authors elaboration based on analyses results)

On day 0, the average sulfate concentration in lettuce was 3.085 mg L^{-1}, and on day 35, it was 3.248 mg L^{-1}. In high-quality plants, sulfate levels are 400 mg L^{-1} (Government Regulation No. 22 of 2021 Group IV). Sulfate levels above a certain threshold indicate that lettuce can develop to its maximum capacity while remaining safe to eat.

On day 0, the average sulfate content in fish was 47.56 mg L^{-1}, and on day 35, it was 56.90 mg L^{-1}. The sulfate concentration in good quality fish is 300 mg L^{-1} (Government Regulation No. 22 of 2021 class III). Sulfate content in fish is affected by pH and water temperature. Day-0 (pH 7.87; temperature 25.76°C) and day-35 (pH 7.76; temperature 28.2°C) at FT show acceptable water quality and increased oxygen concentration, indicating that sulfur will be metabolized in the form of ions like sulfate, lowering hydrogen sulfide formation. Sulfate levels in fish are within the permitted threshold (Government Regulation Number 22 of 2021 Group III), (Muneer et al., 2016; and Junge and Antenen, 2020) suggesting that the tilapia produced is safe to eat. Elemental sulfur helps plants repair photosynthetic damage caused by Fe shortage but it's also linked to hydrogen sulfide (H_2S) in fish (Muneer et al., 2016; Junge and Antenen, 2020). Under aerobic conditions, *Thiobacillus bacteria* convert hydrogen sulfide to sulfate (Kelley et al., 2016).

Potassium concentration analysis. The element potassium is essential for plant flower development. Eutrophication causes high levels of nitrate, phosphate, and potassium in aquaponic systems, which can harm fish and plants (Concepcion et al., 2020; Banerjee and Prasad, 2020).

On days 0 - 35, the average potassium concentration in water is 1.92 - 15.66 mg L^{-1}, as shown in Fig. 7. Potassium concentrations in FT, BT, and HS were 7.31 mg L^{-1}, 7.19, and 6.62 mg L^{-1}, respectively. According to the findings, the average concentration of potassium has increased due to potassium originating from uneaten fish feed settling to the bottom of the FT water, resulting in increased concentrations of dissolved anions and cations in the nitrogen and carbon cycle, as well as dissolved minerals (macronutrients and micronutrients) such as K^+, Ca^{2+}, Mg^{2+}, Na^+, Fe^{2+}, Cu^{2+}, Zn^{2+}, P and S (Konig, 2016; Karim and Baharin, 2019).

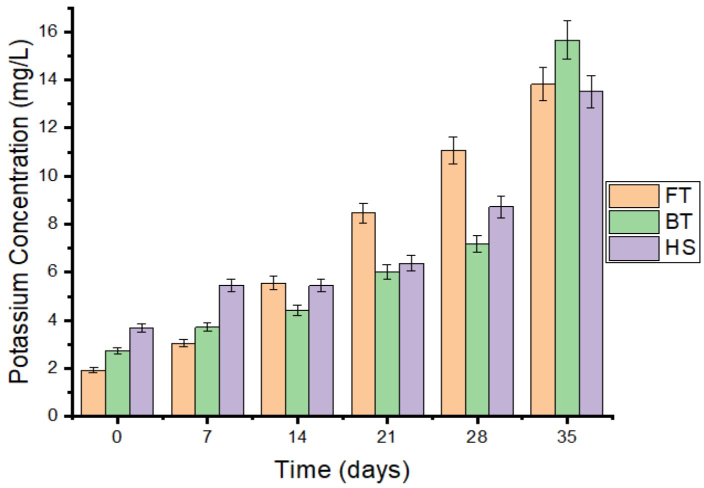


Fig. 7. Relationship of Potassium concentration in water (mg L^{-1}) with time variation (days)
(Source: authors elaboration based on analyses results)

On day 0, the average potassium concentration in lettuce was 4.727 mg L^{-1}, and on day 35, it was 5.115 mg L^{-1}. Plants require potassium levels of 0.1-0.8 percent (akwu et al., 2019). Potassium-deficient plants absorb less water, making them more prone to disease (Junge and Antenen, 2020). There were no old leaves or dead leaf edges on this sample, indicating good lettuce development.

Day-0 fish had a potassium concentration of 33.31 mg L^{-1}, while day-35 fish had a potassium concentration of 44.47 mg L^{-1}. Potassium concentrations of 156-300 mg L^{-1} are recommended for hydroton-flocponics, while high potassium concentrations can benefit plants but harm fish. The fish meal used in this study contained 79.51 mg L^{-1} of potassium per 100 g of feed, resulting in a high average potassium content.

Calcium concentration analysis. In fish and aquatic biota, calcium ions (Ca^{2+}) in water can lower hazardous chemical compounds (NO_2) (Hamid et al., 2020). Fig. 8 shows that the average calcium concentration in water days 0-35 is 5.02 - 19.59 mg L^{-1}. Calcium concentrations in FT, BT, and HS were 9.77 mg L^{-1}, 10.17 mg L^{-1}, and 11.60 mg L^{-1}, respectively. Every week, dolomite lime ($CaMg(CO_3)_2$) was added to the FT to increase the hardness and maintain a steady pH in the FT. For fish culture, a water hardness value of at least 20-180 mg L^{-1} is recommended (Yanes et al., 2020).

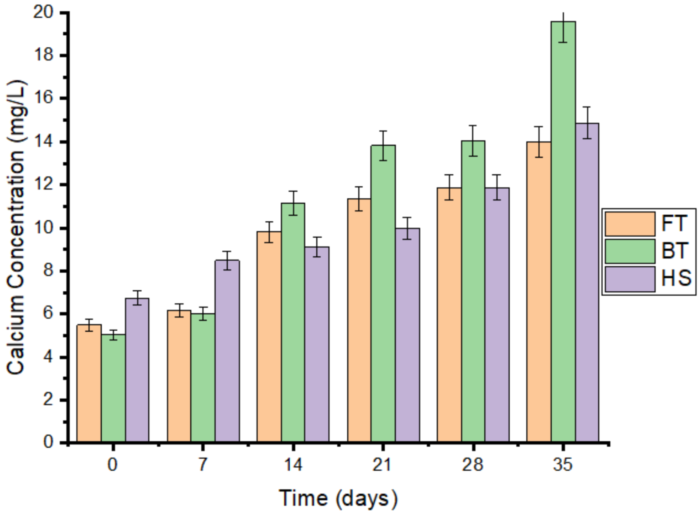


Fig. 8. Relationship of Calcium concentration in water (mg L^{-1}) with the variation of time (days)
(Source: authors elaboration based on analyses results)

Day-0 plants had an average calcium concentration of 14.5 mg L^{-1}, while day-35 plants had an average calcium concentration of 68.65 mg L^{-1}. The high average calcium concentration was impacted by the calcium content of dolomite lime and fish feed. The calcium in the fish feed had a concentration of 125.7 mg L^{-1} in 100 g, while the dolomite lime applied to the FT had a concentration of 66.15 mg L^{-1} in 50 g.

The average calcium concentration in tilapia was 108.5 mg L^{-1} on day 0 and 143.75 mg L^{-1} on day 35. The amount of fish feed consumed is linked to the average high calcium content in tilapia. The calcium content of 100 g of fish feed is 125.7 mg L^{-1}. Low calcium concentrations can produce brittle bones in fish, whereas calcium concentrations were greater than 200 mg L^{-1} can induce corrosion in aquaculture fish water pipes (Cerozi and Fitzsimmons, 2017).

Copper concentration analysis. Cu is a heavy metal that is required for the growth of fish and plants as a micronutrient. Cu metal is a component of enzymes and chlorophyll, and it aids in carbohydrate and protein digestion. However, too much Cu can be hazardous to fish and plants (Edelstein and Ben-Hur, 2018; Ali et al., 2019).

According to Fig. 9, the average Cu content in water (day 0-35) was 0.0038-0.032 mg L^{-1}. Cu values were 0.017 mg L^{-1}, 0.015 mg L^{-1}, and 0.014 mg L^{-1} in FT, BT, and HS, respectively. Cu values of 0.02 mg L-1 are deemed safe for freshwater fish aquaculture and irrigation in agriculture (Government Regulation No. 22 of 2021 class III). Because the Cu content on day 0 exceeded the maximum allowable quality level of 0.03 mg L^{-1}, biofloc was likely not given to the aquaponics system, resulting in poor performance.

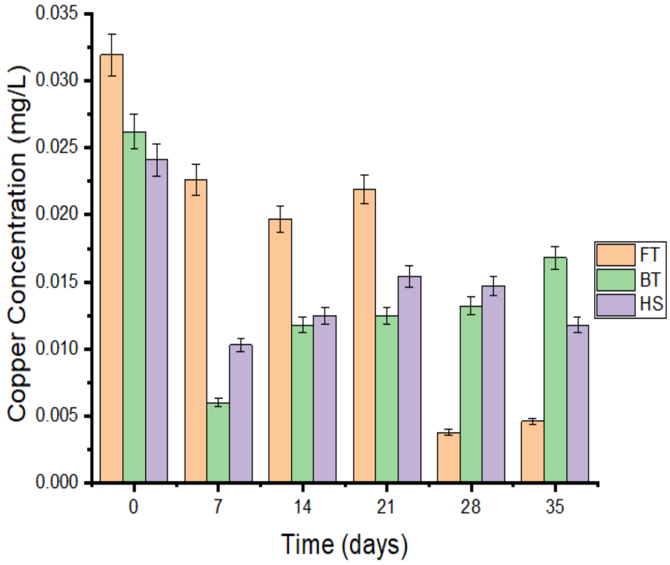


Fig. 9. Relationship of Cu concentration in water (mg L^{-1}) with time variation (days) (Source: authors elaboration based on analyses results)

The average Cu concentration in the FT fell on day 7, showing that the Cu metal had started to be absorbed by the lettuce roots for growth. The average concentration of Cu in BT is the lowest, at 0.006 mg L^{-1}, due to poor absorption of fish feed waste. On the 14th day, the average concentration of Cu in the FT decreased to 0.0197 mg L^{-1} due to the concentration of Cu that flowed into the HS to be absorbed by plants. However, the Cu content in the FT grew again on the 21st day when uneaten fish feed was collected and settled to the pond's bottom. Day 28-35, the average Cu concentration in FT, BT, and HS dropped again; it's thought that Cu is needed by plants and fish for growth (Alloway, 2013; Deswati et al., 2019).

On day 0, Cu lettuce had a concentration of 0.0013 mg L^{-1}, and on day 35, it had a concentration of 0.0023 mg L^{-1}. Cu concentration in quality plants is 0.2 mg L^{-1} (Government Regulation No. 22 of 2021 class IV), hence the lettuce grown in this study is safe to eat.

On day 0, Cu concentrations in fish varied from 0.0045 mg L^{-1} to 0.0047 mg L^{-1} on day 35, Cu concentration is 0.02 mg L-1 in high-quality fish (Government Regulation No. 22 of 2021, Group III). Because the fish absorbed Cu metal as a micronutrient, the rising Cu level indicated that the fish were growing in good health. Cu content grows proportionally to the amount of Cu in the fish feed consumed. Cu concentration in 100 g of fish feed is 0.32 mg L^{-1}.

Iron concentration analysis. In aquaponics systems, Fe deficiency is frequent. Fe is provided as salt for fish feed in aquaponics systems. Fish faeces, on the other hand, is used as a source of nutrients for hydroponic plants in aquaponic systems (Sallenave, 2016).

According to Fig. 10, the average Fe concentration in water (day 0-35) is 0.0138 - 2.03 mg L^{-1}. FT, BT, and HS had Fe values of 0.861 mg L^{-1}, 0.636 mg L^{-1}, and 0.772 mg L^{-1}, respectively. There is currently no acceptable Fe content water quality regulatory threshold for freshwater fish aquaculture or agriculture irrigation (Government Regulation No. 22 of 2021 class III). The average Fe concentration in this study falls every week. On FT, BT, and HS, the highest values (day-0) were 2.03 mg L^{-1}, 1.54 mg L^{-1}, and 1.99 mg L^{-1}, respectively. On day 7, the average Fe concentrations in FT, BT, and HS were 1.97 mg L^{-1}, 1.27 mg L^{-1}, and 1.65 mg L^{-1}, respectively. On the 14th day, the most significant decreases in FT, BT, and HS occurred, with values of 0.52 mg L^{-1}, 0.41 mg L^{-1}, and 0.35 mg L^{-1}, respectively. Similarly, until the 35th day, the average Fe values were 0.146 mg L^{-1}, 0.138 mg L^{-1}, and 0.147 mg L^{-1}. Some Fe was consumed by fish for growth and absorbed by plants for growth, resulting in a drop in Fe content (Deswati et al., 2019; Alloway, 2013).

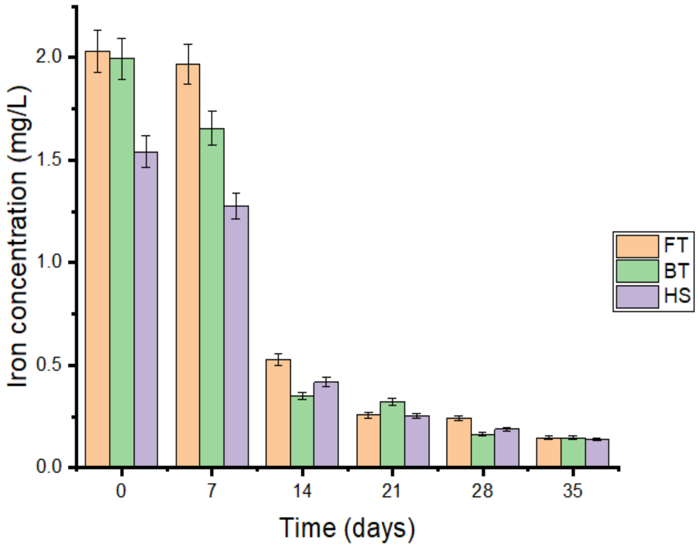


Fig. 10. Relationship of Fe concentration in water (mg L^{-1}) with time variation (days) (Source: authors elaboration based on analyses results)

On day 0, the average Fe concentration in lettuce was 0.0357 mg L^{-1}, and on day 35, it was 0.0442 mg L^{-1}. By increasing the average Fe content, lettuce's potential to grow is proved. The optimal mean Fe content for green plants and fruits in aquaponics systems, on the other hand, has yet to be identified.

On day 0, the average Fe concentration in fish was 0.114 mg L^{-1}, and on day 35, it was 0.147 mg L^{-1}. In fish, Fe is involved in oxygen transfer, electron transport, and cellular respiration, with hemoglobin activity playing a key role (Bartelme et al., 2018). In studies on fish feed taken from 100 g of fish feed, Fe metal levels as high as 5.16 mg L-1 were discovered. This means the Fe need for fish growth in length and weight has been satisfied.

Zinc concentration analysis. In humans, animals, and plants, zinc plays a significant part in metabolic activities (Thangapandiyan and Monica, 2020). Zn metal bioaccumulation occurs in the organs of tilapia in aquaponic farming.

According to Fig. 11, the average Zn concentration in water days 0-35 is 0.106 - 0.894 mg L^{-1}. The average Zn concentration in FT, BT, and HS was 0.447 mg L^{-1}, 0.546 mg L^{-1}, and 0.594 mg L^{-1}, respectively. Freshwater fish cultivation and crop irrigation require a Zn level of 0.05 mg L^{-1}. (Government Regulation of the Republic of Indonesia Number 22 of 2021 class III). In FT, the average Zn concentration (day-0) is higher than the quality standard. BT had the highest average Zn concentration (0.46 mg L^{-1}), indicating that the hydroton-flocponics system had not worked as effectively as it could have. As a result of the plants absorbing Zn for growth, the Zn concentration in HS dropped to 0.10 mg L^{-1}. On days 7-35, significant Zn concentrations in BT and HS were found due to unused fish feed and fish faeces accumulated at the bottom of the fish pond.

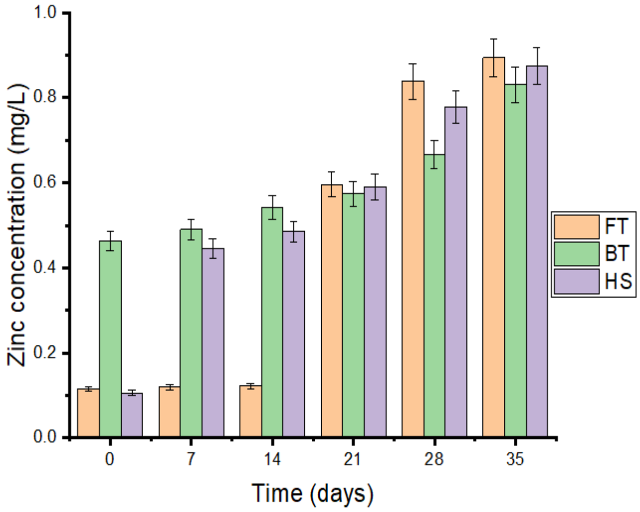


Fig. 11. Relationship of Zn concentration in water (mg L^{-1}) with time variation (days) (Source: authors elaboration based on analyses results)

On day 0, the average Zn lettuce content was 0.274 mg L^{-1}, but on day 35, it was 0.485 mg L^{-1}. Plants of good quality have a Zn level of 2 mg L^{-1} (Indonesian Government Regulation Number 22 of 2021 Group IV). Zn is more easily absorbed than Cu in lettuce on average. The increase in Zn concentration meant the lettuce was flourishing. The concentration of Zn in the lettuce generated in this study is within the acceptable quality guideline, indicating that it is safe to eat.

On day 0, the average Zn content in fish was 0.454 mg L^{-1}, while on day 35, it was 0.843 mg L^{-1}. The fact that fish absorb Zn for growth is demonstrated by increasing the concentration of Zn. The fish feed ingested had 0.69 mg L^{-1} Zn per 100 g of fish feed, resulting in a high average concentration of Zn in the fish. Fish in FT absorb Zn metal through water; however, the high average concentration of Zn in the water is harmful to fish since it impairs their growth and survival.

Analysis of hydroton concentration and composition. Hydrotons were investigated using X-Ray Fluorescence Spectrophotometry to determine their concentration and composition (Nozzi et al., 2018). A good hydroponic planting medium should be able to absorb and supply water while also not affecting the pH of the water, changing color, or rotting readily. Growing media can also be used as a root handle and a nutrient solution intermediate. Hydroton is a type of growing media comprised of spherical clay that has been heated to high temperatures.

The oxide composition has a strong influence on the reusability of hydrotons. Table 1 shows the amount of metal oxide in the hydroton before and after use.

Table 1.

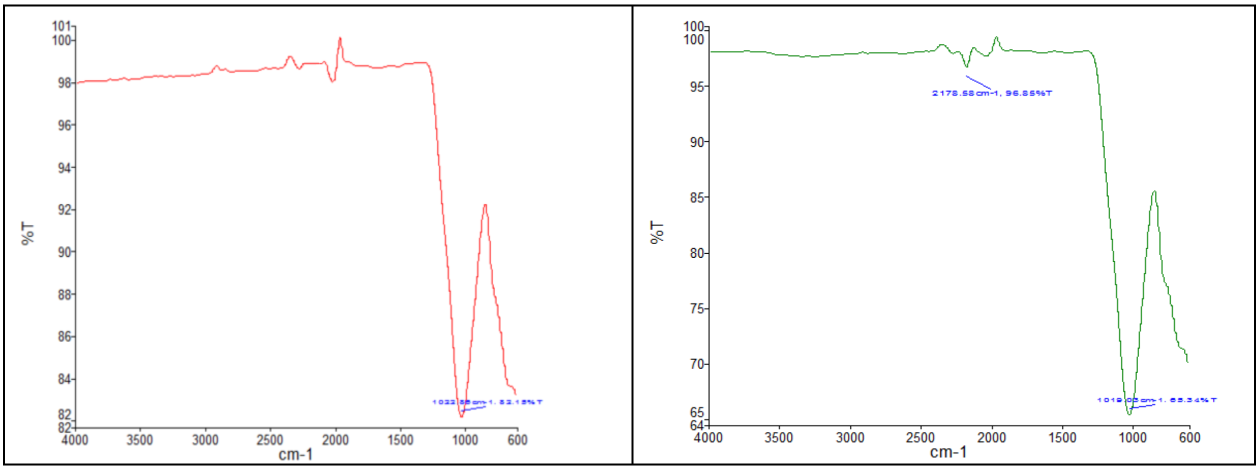
Characterization of XRF on hydroton

Oxide Compounds	*Hydroton Concentration Before use (%)*	*Hydroton concentration After use (%)*
MgO	2.201	10.671
Al_2O_3	19.811	7.124
SiO_2	56.372	26.042
P_2O_5	1.176	3.686
SO_3	-	7.352
K_2O	3.876	5.001
CaO	2.399	4.671
TiO_2	0.985	1.668
V_2O_5	0.027	0.055
Cr_2O_3	0.052	0.093
MnO	0.083	0.199
Fe_2O_3	12.312	31.003
NiO	0.023	0.087
CuO	0.012	0.04
ZnO	0.066	0.274
Ga_2O_3	0.004	0.015
As_2O_3	0.002	0.012
Rb_2O	0.015	0.061
SrO	0.021	0.084
Y_2O_3	0.004	0.02
ZrO_2	0.034	0.141
Ag_2O	0.391	1.007
Eu_2O_3	0.088	0.186
PbO	0.008	0.027
Cl	0.041	0.48

Hydroton oxide composition includes: SiO_2 56.3%, $Al_2O_3$19.8%, Fe_2O_3 12.3%, K_2O 3.87%, CaO 2.39%, MgO 2.20%, P_2O_5 1.17% and other organic materials 1%. However, the concentration of SiO_2 and Al_2O_3 in hydrotons was reduced to 26.04% and 7.24% after being used as growing media. The addition of macronutrients and micronutrients to the FT was absorbed by the hydrotons so that the concentration of metal oxides in the hydrotons increased including Fe_2O_3 to 31.12%, K_2O to 5.01%, CaO to 4.67%, MgO to 10.67%, P_2O_5 to 3.68 % and SO_3 7.35%. The concentration of macro and micronutrients increased due to uneaten fish feed, fish manure, and the addition of dolomite lime.
(Source: authors elaboration based on analyses results)

Characterization of Functional Groups in Hydroton. FTIR was used to examine the hydrotons' functional groups. The FTIR results on hydrotons before and after use are shown in a spectrum graph with the x-axis representing wavenumber (cm^{-1}) and the y-axis representing the % transmittance value. Fig. 12 depicts the results of the FTIR spectrum.

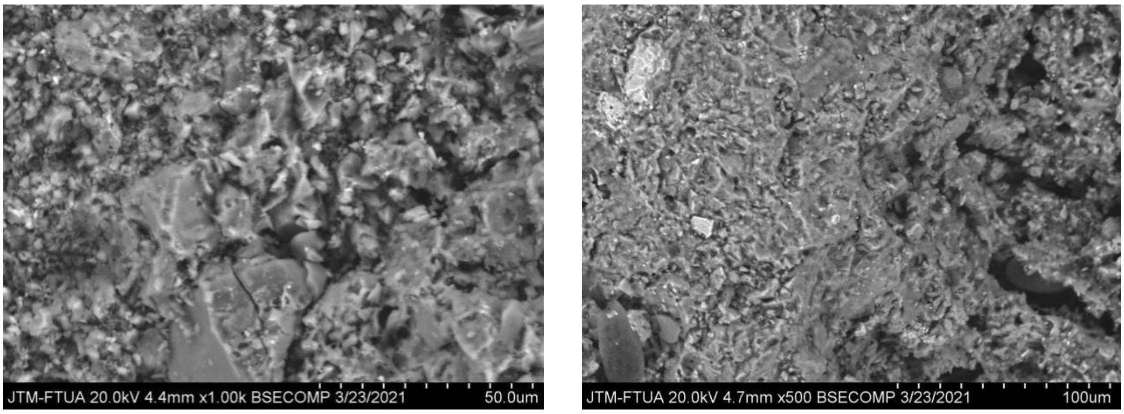
The FT-IR spectrum of Hydroton was measured at wavenumbers spanning from 600 to 4000 cm^{-1}. There is no discernible variation between hydroton before and after use in Fig. 12. The peaks that showed on hydrotons before and after usage were acute absorption peaks at 1022 cm^{-1} on hydrotons before use and 1019 cm^{-1} on hydrotons after use, which were Al-O stretching vibrations. as well as Si–O. The OH^-buckling vibration of the water molecules adsorbed on the hydroton after use causes absorption in the wavenumber band of 2178 cm^{-1}.



(a) (b)

Fig. 12. Hydroton characterization with FTIR (a) before use and (b) after use
(Source: authors elaboration based on analyses results)

Surface characterization of hydroton growing media. Hydroton is also utilized as a growing medium since it includes pores that allow nutrients to be absorbed. Because hydrotons are comprised of clay, they must be examined using scanning electron microscopy (SEM) to identify their shape and pore size. The bigger the amount of water absorbed, the higher the concentration of organic materials. The hydroton stores a lot of water due to its high organic matter content (Rosman et al., 2019).



(a) (b)

Fig. 13. Hydroton characterization using SEM with 1000 times magnification
(a) before use and (b) after use
(Source: authors elaboration based on analyses results)

The hydroton's pore structure and surface form indicate that it is porous. There are many pores with a pore size of 4.4 mm in Hydroton pores before they are used. Hydrotons have more particles in the grain as a result of their structure (Pouramini et al., 2019). After use, the hydroton's surface accumulates many tiny particles, resulting in a rough surface with a porous structure. With a pore size of 4.7 mm, the surface of Hydroton alters during use.

According to the above description, using hydroton as a lettuce planting medium has several advantages, including: (1) having a high pore space means fewer blockages, allowing water to flow more freely, making hydroton a growing medium in a tidal aquaponic system; (2) is a renewable and environmentally friendly technology; (3) Reusable; (4) Able to maintain plant roots to always oxidize; 5) Easy to use; and 6) Good microbial colonization. The downsides of employing hydroton include: (1) low water holding capacity, which necessitates finding a technique to keep the substrate moist; (2) high cost; and (3) potential pump and water supply line difficulties.

Conclusions. The use of lettuce and tilapia in hydroton-flocponics was examined. In HS, the growing medium was hydroton. The amounts of DO, BOD, COD, sulfate, Ca, K, and Cu, with the exception of phosphate and Zn, are generally within permitted quality criteria, but the legal levels for Fe have not been identified. The hydroton investigation revealed that it has a high porosity to prevent obstructions, the capacity to keep plant roots oxidizing at all times, is environmentally friendly, recyclable, reused, and simple to use, and is an excellent colony for the microbial population. In a hydroton-flocponic system with no yellowing, wilting, or nutrient deficit, hydroton can improve water quality and macro-micro nutrients.

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

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Authors:
Deswati, Department of Chemistry, Faculty of Mathematics and Natural Science, Andalas University, Kampus Limau Manis, Padang, 25163 Indonesia, e-mail: deswati@sci.unand.ac.id; deswati_ua@yahoo.co.id
Safni, Department of Chemistry, Faculty of Mathematics and Natural Science, Andalas University, Kampus Limau Manis, Padang, 25163 Indonesia, email: safni@sci.unand.ac.id
Latisha Putri Isara, Department of Chemistry, Faculty of Mathematics and Natural Science, Andalas University, Kampus Limau Manis, Padang, 25163 Indonesia, latishaputrii@gmail.com
Hilfi Pardi, Department of Chemistry Education, Faculty of Teacher Training and Education, Raja Ali Haji Maritime University, Senggarang, Tanjungpinang, Indonesia, hilfipardi@umrah.ac.id.

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