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Carbonized Rice Husk and Cocopeat as Alternative Media Bed for Aquaponic System

(Sekam Bakar dan Sabut Kelapa sebagai Media Alternatif untuk Sistem Akuaponik)

MUHD NAZRUL HISHAM ZAINAL ALAM, NUR SYAHMI IZZATI ALI OTHMAN, SANI AMRIL SAMSUDIN, ANWAR JOHARI, MIMI HARYANI HASSIM & MOHD JOHARI KAMARUDDIN*

ABSTRACT

The study evaluates the suitability of carbonized rice husk and cocopeat substrates as alternative media bed in aquaponics unit for cultivation of red Nile tilapia and Gynura procumbens*. Area occupied by the aquaponics unit is about 4.5 m^2 and it was operated under equatorial climate conditions. Various substrates namely lightweight expanded clay aggregate (LECA), cocopeat, carbonized rice husk and a mixture of cocopeat-rice husk at ratio 1:1 were prepared using polybags for growing of the longevity spinach. The resultant effects from fish cultivation and plants growth on the water qualities and nitrification efficiency of the aquaponics unit were reported. The aquaponics unit were operated for twelve weeks and the values of pH, temperature, and dissolved oxygen level were measured to be within the range of 6.4-6.9, 27.7-29^{o}C, and 5.5-7 mg·L^{-1}, respectively. Survival rate for fish was 98% with specific growth rate (SGR) and food conversion ratio (FCR) of 6.9% per day and 1.13, respectively. Nutrient deficiency was not evident and plants showed healthy growth with harvest yield ranging between 3.6 and 3.9 kg·m^{-2}. Results attained signified the suitability of utilizing carbonized rice husk and cocopeat as alternatives media bed compared to commercial media bed such as LECA.*

Keywords: Aquaponics; Gynura procumbens*; LECA; media grow bed; red Nile Tilapia*

ABSTRAK

Kajian ini menilai kesesuaian bahan sekam bakar dan sabut kelapa sebagai media alternatif dalam unit akuaponik bagi pembiakan tilapia merah dan Gynura procumbens*. Keluasan unit akuaponik yang dibentuk ialah 4.5 m^2 dan operasi dijalankan di bawah keadaan cuaca khatulistiwa. Pelbagai bahan termasuk gumpalan tanah liat ringan (LECA), sekam bakar, sabut kelapa dan campuran sabut kelapa dan sekam bakar pada nisbah 1:1 disediakan menggunakan polibeg bagi pertumbuhan sambung nyawa. Kesan paduan daripada pembiakan ikan dan pertumbuhan pokok pada kualiti air dan keberkesanan tindak balas nitrifikasi unit akuaponik dilaporkan. Unit akuaponik tersebut beroperasi selama dua belas minggu dan nilai pH, suhu dan tahap oksigen terlarut didapati berada dalam lingkungan 6.4-6.9, 27.7-29^{o}C dan 5.5-7 mg·L^{-1}. Kadar kelangsungan hidup ikan adalah 98% dengan kadar pertumbuhan tentu (SGR) dan kadar penukaran makanan (FCR) ialah masing masing pada 6.9% per hari dan 1.13. Tiada kesan kekurangan nutrien dan pokok menunjukkan pertumbuhan yang sihat dengan hasil tuaian berkisar antara 3.6 hingga 3.9 kg.m^{-2}. Keputusan yang diperoleh membuktikan kebolehsesuaian dalam penggunaan bahan sekam bakar dan sabut kelapa sebagai media altenatif berbanding media komersil seperti LECA.*

Kata kunci: Akuaponik; Gynura procumbens*; LECA; media pertumbuhan; Tilapia Merah*

INTRODUCTION

A basic aquaponics setup combines fish farming (aquaculture) with hydroponic agricultural farming. A synergy between fish farming and hydroponics creates a well-designed aquaponics system where both plants and fish can coexist in a balanced ecosystem (Maucieri et al. 2018). One of the important design element of aquaponics system is the establishment of the plant growing area. Three of the most commonly employed design are the (i) media bed units (ii) the nutrient film technique (NFT) units and (iii) the deep water culture (DWC) units (Maucieri et al. 2018; Petrea et al. 2016). This work focuses on the choice of substrates for the media bed of aquaponics unit. Gravel based substrates and lightweight expanded clay aggregate (LECA) are two types of medium typically utilized for commercial aquaponics units worldwide mainly due to their compatibility. These types of substrates have surface area between 250 and 400 m^2/m^3. Gravels may be a little bit overweight but LECA is very lightweight compared to other substrates. Both substrates are inert materials and have been reported to obtain exceptional water retention capacities and good production rate in comparison to other types of medium (Bakiu et al. 2017; Olademeji et al. 2018). Despite the advantages, the usage of gravels may cause the growth of algae in the system where else LECA substrates are relatively costly. In Malaysia, 25 L of LECA substrates cost about RM70 (~17 USD) and can only be purchased from oversea supplier. Clearly, low cost substrates as alternative to LECA are needed if farmers in Malaysia were to adopt such aquaponics system for growing plants and cultivating fish. Potential substrates include cocopeat and carbonized rice husk. Cocopeat is the 'coir dust' - a by-product produced when processing coconut husks where else carbonized rice husk is the rice husk ash after combustion in energy production process using rice husk (Noor Syuhadah & Rohasliney 2012). Report indicated that over 5000 kg of coconut waste per hectare per year are being produced. Also, it was estimated nearly 400,000 metric tonnes of rice husk are produced in Malaysia (Fazlil Ilahi & Ahmad 2017; Noor Syuhadah & Rohasliney 2012). Finding alternative use for these wastes is one of the motivation of this work. Most importantly, both carbonized rice husk and cocopeat substrates are easily accessible by local farmers at very low cost. For every 25 L volume, carbonized rice husk and cocopeat cost only about RM15 (3.6USD) and RM5 (1.2USD), respectively.

In the present work, red Nile Tilapia (*Oreochromis niloticus*) and longevity spinach (*Gynura procumbens*) were cultured in a small scale aquaponics unit. To the best of our knowledge, no attempt has been made for such fish-plant pairings. Longevity spinach is an herbaceous plant that gave benefits to many people. Tilapia on the other hand is one of the major contributors for fresh water aquaculture fisheries production in Malaysia. The performance of carbonized rice husk and cocopeat as media bed was evaluated by observing the growth of plants and fish cultivated over the period of 12 weeks. Combine effects of proposed media and plant-fish pairings on the water quality were also assessed where physical parameters measured include pH, temperature, ammonia level, and nitrite and nitrate concentration.

Materials and Methods

Establishment of Small Scale Aquaponics Unit

A small scale aquaponics unit with a foot print of approximately 4.5 m^2 was realized in this study. The schematic of the aquaponics unit is presented in Figure 1. Rectangular shape basins with flat bottom made of polyethylene were used in building the main structure of the aquaponics unit. The fish tank (I) formed the base of the aquaponics unit and has a total volume of approximately 1100 L, 1.65 m (length) × 0.6 m (height) × 1.1 m (width). A submersible pump (RS-1800 submarine water pump, Daya Aquatic Sdn. Bhd.) was used to pump water from the fish tank to the filtration unit (II). In this setup, the filtration unit was placed 1.5 m from the ground. The filtration unit was filled with white high density filter sponge and numbers of flower type Bio-rings and Bio-balls. Water exits the filtration unit from the bottom of the filtration unit into the plant growing area.

Four rectangular shape basins with dimension of 0.85 m (length) × 0.25 m (height) × 0.55 m (width) was utilized to accommodate a plant growing area (III) consisted of LECA (P1), cocopeat (P2), carbonized rice husk (P3) and a mixture of cocopeat-rice husk at ratio 1:1 (P4) substrates. Water from the filtration unit flows into the plant growing area at the same flow rate of 360 litre·hr^{-1}. The water is regulated using a ball valve (V) - installed along the water line at the inlet of each growing area (P1 to P4) and runs underneath the plants. Flood-and-drain media bed was realized at each growing area (P1 to P4) using a siphon flushing mechanism. In such system, water will automatically drain into the sump tank (IV) once the water level in each container reaches to a height of the mechanical siphon stand pipe of about 5 cm. This is equivalent to 30-40% of the height of the polybag used for plant cultivation.

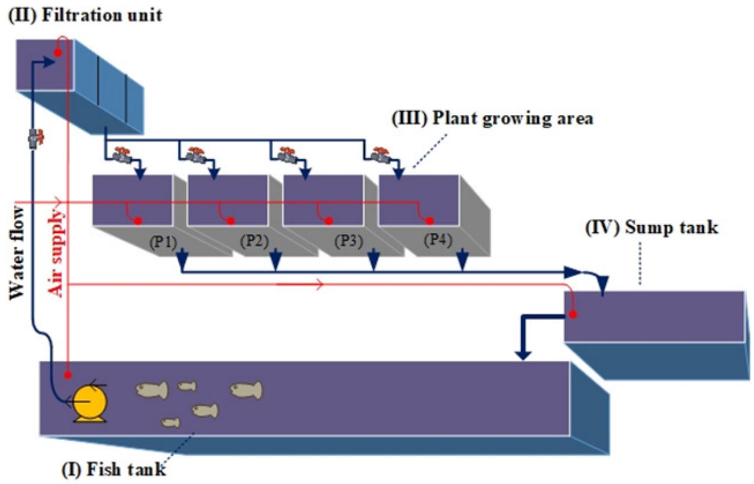

FIGURE 1. Schematic of the small scale aquaponics system unit designed for the present study. The unit consisted of a fish tank (I), filtration unit (II), plant growing area (III) and the sump tank (IV). Water is pumped from the fish tank to the filtration unit using a submersible pump and gravitationally flows down to the plant growing area, passing through the sump tank before went back to the fish tank

A sump tank with dimension of 1.2 m (length) × 0.24 m (height) × 0.8 m (width) was placed in between the plant growing area and the fish tank. It is the last water collection point to trap and remove small particles before the water flows back to the fish tank. All the main structure is connected using a polyvinyl chloride (PVC) pipes ($Ø_i$ ~ 25 mm). Aeration was provided to each structure using an air pump (RS-16000 air pump, Daya Aquatic Sdn. Bhd.). Air stones are connected to the end of every air lines and place at the bottom of a tank to promote good oxygen transfer. Since the filtration unit is located higher than any other structure, water gravitationally flows down into the plant growing area, pass through the sump tank before went back to the fish tank. This minimizes energy consumption as no pump is needed for transport of water from the filtration unit to the fish tank. Temperature of the water was not controlled but sun shading net was used to prevent direct exposure to sunlight and reduce algae growth in the system.

CULTURING OF LONGEVITY SPINACH AND CULTIVATION OF TILAPIA FISH

The plant growing area consisted of longevity spinach plants grown on four different types of media bed. These include LECA (P1), cocopeat (P2), carbonized rice husk (P3) and a mixture of cocopeat-rice husk (P4) substrates. A polybag (13 cm × 13 cm) was utilized for planting of the longevity spinach. Media bed were added in each polybag such that the media occupied nearly 75-80% of the total volume of the polybag. Culturing of longevity spinach were done using a plant stem with nine leaves and 16-17 cm long. It is recommendable to use polybag that has been pierced and consisted of holes. This is essential to allow water to diffuse into the media bed and provide water supply for plant growth. Each container (P1 to P4) contained 24 bags of longevity spinach plants - arranged in orderly fashion.

Stocking of the Red Nile Tilapia was done immediately after the plant growing area has been prepared. Twenty Tilapia with initial mean weight of 265 g were stocked into the fish tank. Volume of water in the tank was 820 L i.e. about 80% of the total volume of the fish tank. Typical acclimatization method was applied to properly introduce the Tilapia fish into the fish tank. All fish were fed with commercial diets (Star Feed TP2) on daily basis and approximately 20 L of the water was added into the fish tank on weekly basis to replenish water losses due to evaporation.

CHARACTERIZATION OF SUBSTRATES PHYSICAL AND CHEMICAL PROPERTIES

Media bed physical properties evaluated include bulk density, water retention capacity and porosity. In order to determine the bulk density, substrates were first filled in a 100 mL beaker. It is important to make sure that the substrates are completely packed within the beaker to eliminate any void spaces. Bulk density was calculated by dividing substrates net weight (g) by 100 mL i.e. the volume of beaker that has been filled with substrates. Calculation of bulk density was based on (1):

$$\text{Bulk density},\left(g{\cdot}mL^{-1}\right)=\frac{W_2-W_1}{beaker\ volume} \tag{1}$$

where W_2 is the weight of beaker and sample (g); W_1 is the weight of beaker (g); and V is the volume of the beaker (mL).

The water retention capacity was determined using the oven-drying method (ASTM 2010) as described in Zhang et al. (2012). Ground sample were placed in aluminum weighing dish and weighed using a digital balance. Then, both the aluminum dish and sample were dried in an oven at 105°C. The dish containing the dried sample were let to cool to room temperature inside a desiccator and weighed again. The last two steps are repeated until constant weight is achieved. The water retention capacity was calculated according to (2):

$$\text{Water retention capacity},(\%)=\left(\frac{WW-DW}{WW}\right)\times 100 \tag{2}$$

where WW is the wet weight of the dish and sample (g); and DW is the dry weight of the dish and sample.

A pycnometer method reported in Zhang et al. (2012) was adopted to calculate substrates porosity. Approximately 33 mL of sample was added into a 100 mL measuring cylinder. Then, distilled water was carefully poured over the sample until water completely covered the top surface of the sample. Air bubbles within the sample were removed by gently shaking the cylinder. A wire mesh screen was placed on top of sample to avoid materials from floating once submerged in water. Finally, materials porosity was calculated from (3):

$$\text{Porosity},(\%)=\left(\frac{V_i-V_f}{V_s}\right)\times 100 \tag{3}$$

where V_i is the combined volume of the sample and added water (mL); V_f is the final total volume of the sample and added water (mL); and V_s is the volume of the sample (mL).

As for chemical properties, each substrate (P1 to P4) were analyzed for total Nitrogen, *N*, Phosphorus, *P*, Potassium, *K*, Calcium, *Ca*, Magnesium, *Mg*, Boron, *B*, Molybdenum, *Mo*, Iron, *Fe*, Manganese, *Mn*, and Sodium, *Na* using Merck Spectroquant® NOVA60 spectrophotometer. These are common macro- and micronutrients needed for plant growth.

WATER QUALITY ANALYSIS

During the course of this study, 1 liter per sample was taken from three different sampling points namely at the fish tank, effluent from the filtration unit and effluent from the plant growing area. Temperature, pH and dissolved oxygen levels were measured using a standard standalone probes where else a digital multi-parameter water checker (Hannawater tester Model HL 83099) was utilized to measure the content of ammonia (NH_3), nitrite-nitrogen (NO_2^-), and nitrate-nitrogen (NO_3^-) in the water sample. The percentage of NH_3, NO_2^- and NO_3^- removal as water passes through different parts of the aquaponics unit was calculated using the formula reported by Effendi et al. (2015) as follows: -

$$\%\text{Reduction} = \frac{a-b}{a} \times 100 \quad (4)$$

where a is the concentration at the influent (mg·L^{-1}); and b is the concentration at the effluent (mg·L^{-1}).

ASSESSMENT OF PLANT AND FISH GROWTH PERFORMANCE

The progress of longevity spinach plant growth was assessed by measuring the height of the plant on weekly basis. The height of the plants was taken from leaf buds to the tips of the roots. Plant weight was only measured at week 1 (initial) and week 12 (final) to check for overall weight gain over the period of twelve weeks. This was done by carefully removing the plants from the polybag and weighed it using a digital balance.

Growth performance of the Tilapia was evaluated based on the fish weight. Four fish were randomly selected from the fish tank to assess the average size of fish on weekly basis. Measurements were repeated three times (triplicates). Percentage (%) weight gain was estimated every week based on the differences of fish weight using (5):

$$\text{weight gain}(\%) = \left(\frac{\textit{Final weight of fish}(g) - \textit{Initial weight of fish}(g)}{\textit{Initial weight of fish}(g)}\right) \times 100\ \% \quad (5)$$

Fish relative growth rate (RGR) and specific growth rate (SGR) were calculated based on the differences between fish weight at week 12 and fish weight at week 1 using (6) and (7), respectively:

$$\text{relative growth rate}(RGR) = \frac{\textit{weight gain}(\%)}{\textit{duration of experiment}(day)} \quad (6)$$

$$\text{specific growth rate}(SGR) = \frac{Ln(\textit{final weight gain of fish}(g))}{\textit{duration of experiment}(day)} \times 100 \quad (7)$$

Finally, total food conversion ratio (FCR) for the Tilapia was calculated at the end of the experiment i.e. at week 12 using (8):

$$\text{food conversion ratio}(FCR) = \frac{\textit{Total feed consumed by the fish}(kg)}{\textit{Total growth of fish}(kg)} \quad (8)$$

RESULTS AND DISCUSSION

WATER QUALITY OF THE AQUAPONICS UNIT

Water temperatures at all parts of the aquaponics system did not vary more than 1.5 degrees between 27.5°C and 29°C. The water temperature was not controlled but clearly, placement of the aquaponics unit under a transparent roof and installation of the sun shading net have successfully retained the water temperature levels within acceptable limits. The pH levels in the aquaponics unit was found to vary between pH6.2 and pH6.85. During starting-up of the aquaponics unit, unchlorinated tap water was used to fill up the fish tank where pH of the water in the fish tank was recorded to be slightly above pH7. As the system started to run for which the nitrogen cycle begun to establish within the aquaponics system, the pH level in the fish tank became slightly acidic at pH6.5-6.6. DO level in the aquaponics unit presented in this study ranged between 5.6 and 6.8 mg·L^{-1}. Depletion of DO level did not happen signified that the aeration strategy (air flow was set to operate at 70 liter·min^{-1}) employed was sufficient to keep DO level in the water above the critical limit which is about 3-4 mg·L^{-1} (Yildiz et al. 2017). Lowest DO level recorded was in the fish tank where the DO level vary between 5.6 and 6.0 mg·L^{-1}.

Figure 2 presents the data for the nitrogen cycle of the aquaponics unit developed in this study. It shows the weekly variation of the ammonia (NH_3), nitrite (NO_2^-) and nitrate (NO_3^-) concentrations at various parts of the aquaponics unit. In our study, analytical grade standards were used to measure only the concentration of NH_3 in the water. As shown in Figure 2(a), the content of NH_3 at the effluent of the filtration unit (S2) is ranged between 0.22 and 0.24 mg·L^{-1} compared to the amount of NH_3 in the fish tank (S1) where the concentration of NH_3 varied slightly between 0.26 and 0.28 mg·L^{-1}. Reduction of NH_3 content was calculated to be about 20-21%. Moreover, the level of NH_3 continued to drop down to about 0.15-0.2 mg·L^{-1} i.e. another 35-37% NH_3 reduction depending on the type of media bed used (S3a-S3d) as the water passed through the plant growing area (Figure 2(b)). Almost similar trend was also observed for the level of nitrite (NO_2^-) in the aquaponics unit. As shown in Figure 2(c), accumulated concentration of NO_2^- in the fish tank was as high as 0.35-0.37 mg·L^{-1}. The amount of NO_2^- at the effluent of the filtration unit was reduced by nearly 30% to approximately 0.25-0.27 mg·L^{-1}. Comparably to the NH_3 profile, NO_2^- levels were further reduced by at least 35-40% i.e. down to the range between 0.15 and 0.18 mg·L^{-1} after passing through the plant growing area (Figure 2(d)). Contrary to the variation of NH_3 and NO_2^- levels, there was an increase in nitrate (NO_3^-) concentration by 20-21% i.e. from 14.5 mg·L^{-1} at the fish tank up to nearly 17.5 mg·L^{-1} after exiting the filtration unit (Figure 2(e)). Also noticeable in Figure 2(f), the level of NO_3^- in the water was no longer increasing but decreased in the range of about 28-29% to average concentration values

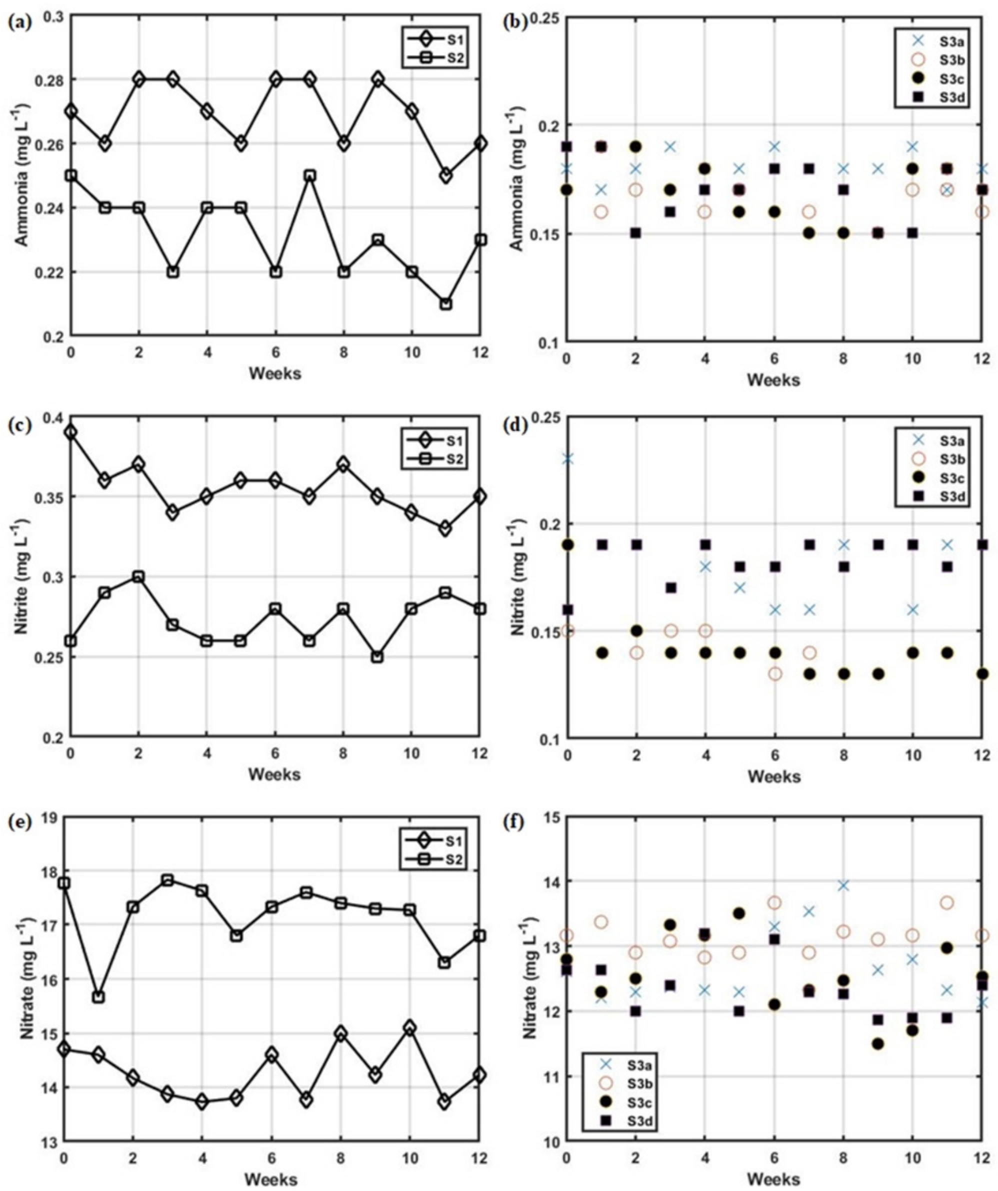

FIGURE 2. Weekly variations of ammonia (NH_3), nitrite (NO_2^-) and nitrate (NO_3^-) in the aquaponics systems for the Tilapia fish and longevity spinach pairings. Water samples were taken from various parts namely from the fish tank (S1), effluent from the filtration unit (S2), effluent from LECA media bed (S3a), effluent from cocopeat media bed (S3b), effluent from rice husk media bed (S3c), effluent from rice husk-cocopeat mixture media bed (S3d) and from the sump tank (S4)

of 12.5-13.5 mg·L^{-1} at the effluent point of the plant growing area.

Results presented in Figure 2 clearly underlining the progress of the nitrification process that taken place in the aquaponics unit. Theoretically, under aerobic conditions, NH_3 excreted by fish will first be oxidised to intermediates component NO_2^- by *Nitrosomonas* bacteria. Subsequently, NO_2^- produced from the first step of the nitrification process is then oxidised to NO_3^- by *Nitrobacter* bacteria (Lam et al. 2015). This explained the variation of NH_3, NO_2^- and NO_3^- profiles evident within the aquaponics unit. At the effluent of the filtration unit (S2), NH_3 and NO_2^- concentrations were generally decreasing whilst NO_3^- levels increased. This is because the nitrification process began at the biofiltration counterpart of the filtration unit. A biofilter of aquaponics unit is designed specifically for colonization of nitrifying bacteria. It provided spaces for bacteria to immobilize and receive sufficient oxygen supply for nitrification process. Further reduction of NH_3 and NO_2^- concentrations at the plant growing area indicated that the nitrification process continued to progress at the plant growing area. Reduction of NH_3 and NO_2^- levels coincided with our earlier claim on the pH reduction at the same sampling point (S3a-S3d) where all were thought to be an indication of the actions of the nitrifying bacteria presence within the plant growing area (Schmautz et al. 2017; Wahyuningsih et al. 2015). A significant reduction of NO_3^- at the effluent of the media bed was a direct result of nitrate consumption by plants. The NO_3^- level did not escalate and remained stable within the range of 12.5-13.5 mg·L^{-1}. Overall, total removal rate of NH_3 and NO_2^- was calculated to be about 47% and 60%, respectively. Low levels of NH_3 and NO_2^- (i.e. below 0.5 mg·L^{-1}) and satisfactorily NO_3^- uptake by plants suggesting that the aquaponics unit (1) contained optimal plants to fish ratio and, (2) microbial community (mainly *Autotropic nitrifiers*) needed for sustainable aquaponics operation has been fully developed (Delaide et al. 2017).

GROWTH PERFORMANCE OF RED NILE TILAPIA

The growth of red Nile tilapia in terms of its weight gain during twelve weeks of cultivation can be seen in Figure 3. In present study, tilapia fish with an average initial weight of 265 + 11.37 g reached a final average size of 595 + 56.85 g and thus, recording a mean weight gain of about 330 g after twelve weeks of growth period. A steady growth was observed for the first five weeks. Then, fish growth inclined rapidly between week 5 and week 10 before came to a steady-state in the latter stage of the experiment. The growth trend for Tilapia evident in this work followed a sigmoidal pattern with specific growth rate (SGR) of 6.9% per day - comparable to Gompertz growth curve as reported in Gullian-Klanian and Arámburu-Adame (2013). Throughout the course of the study, total feed consumed by all twenty tilapia fish was about 7.48 kg. Since average weight gain of a single fish is 330 g, this gives a total growth of all twenty fish of approximately 6.6 kg (330 g × 20 fish). Therefore, the food conversion ratio (FCR) attained was 1.13. The FCR value can be translated as the amount of feed required to produce 1 kg of meat. Lower FCR values means feed given to the fish is effectively consumed. In fish farming activities, fish feed is relatively costly. In this respect, if FCR can be lowered, expenses for fish feed would be reduced as well and thus, increase operation revenue. The values of SGR and FCR for Red Nile tilapia fish grown in this aquaponics unit is low compared to the ones attained in some of the published works over the same growth period (Fazlil Ilahi & Ahmad 2017; Gullian-Klanian & Aramburu-Adame 2013; Salam et al. 2014). This is due to the size of the fish during stockings in the beginning of the aquaponics operation. Our setup started with tilapia fish of initial weight about 265 g whilst most fish farmers initiated their aquaponics unit using fish with initial weight less than 25 g. It is noted that smaller fish especially those that weights approximately 20-25 g would have SGR value as high as 7-8% per day and FCR value within the range of 1.7 and 2.0. In other words, compared to the larger size fish (weight >100 g), stocking of small fish would result in a rapid growth that consumes significant amount of feed. Survival rate of the present aquaponics unit was 98% where one fish died after two weeks of cultivation. It has been reported that small losses/death are typical as fish adjusting to a new environment. Unbalance nitrogen compounds namely ammonia, nitrites and nitrates in the early stage of the cultivation could also be the cause of fish death prior to sustainable cycle in aquaponics unit (Delaide et al. 2017). Despite the losses, survival rate is still within acceptable limit i.e. above 90% (Fazlil Ilahi & Ahmad 2017). In our aquaponics unit, stocking density is relatively low; which is about 30 fish per cubic meter. This is to prevent any heterogeneous fish growth whilst assuring adequate food and oxygen supplies. Uneaten fish feed was removed instantaneously to avoid overfeeding of fish that could results in excessive production of ammonia (Delaide et al. 2017). Also, uneaten fish pellets may have sunk to the bottom of fish tank and thus, affecting water quality as the level of total suspended solid in the fish tank would undesirably increase over time.

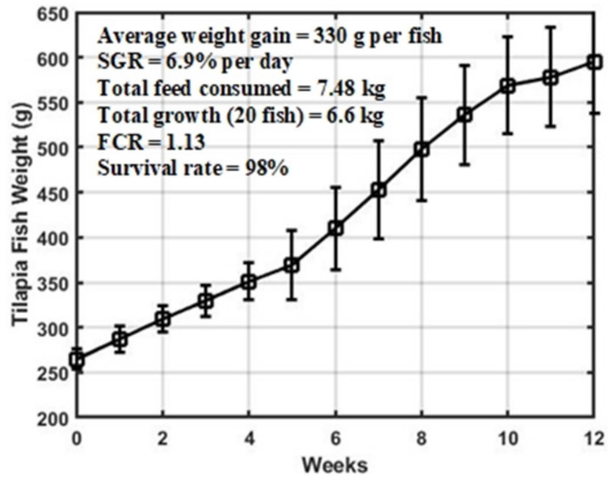

FIGURE 3. Red Nile Tilapia fish weight gain over the period of twelve weeks' cultivation. Measurements were attained as mean values from ten fish (randomly picked) and error bars indicated the standard deviation of each measurements. Inset shows the information pertaining to average weight gain, SGR, FCR and survival rate

EFFECTS OF DIFFERENT SUBSTRATES ON LONGEVITY SPINACH GROWTH

Table 1 presents the differences of physical properties namely bulk density, water retention capacity and porosity for all the four substrates mixture evaluated in this study. These include LECA, cocopeat, carbonized rice husk and carbonized rice husk-cocopeat mixture. It was found that the bulk density of cocopeat, carbonized rice husk and carbonized rice husk-cocopeat mixture are nearly similar to one another i.e. between the range of 0.1 and 0.14 $g\cdot cm^{-3}$ and much lower than the bulk density of LECA which is about 0.383 $g\cdot cm^{-3}$. Nonetheless, bulk density of all four substrates are less than 1 $g\cdot cm^{-3}$ and can be considered as lightweight materials (Boudaghpour & Hashemi 2008). Bulk density is also a measurement of efficiency that describes how particles are pack together in confined medium. It is highly dependent on the particle shape, particle size, and particle size distribution of the substrates. LECA is mainly semi-rounded in shape and available at various sizes ranging between 5 and 15 mm in diameter (Boudaghpour & Hashemi 2008). Differently from LECA, cocopeat and carbonized rice husk are loosely packed because of the heterogeneity nature of the substrates. The size of individual pieces of cocopeat varied widely within few millimetres range (0.5 - 4 mm) (Kumarasinghe et al. 2015) where else the size of carbonized rice husk pieces distributed over the range between 5 and 150 mm (Venkatanarayanan & Rangaraju 2013). Clearly, significant variation in particle size distribution of cocopeat and carbonized rice husk substrates resulted in a much lower bulk density values compared to LECA.

Water retention capacity is a very important agronomic characteristic and it differed from one media bed to another. Our measurements show that LECA has the highest water retention capacity i.e. at 37% (wt/wt) followed by cocopeat and cabonized rice husk at 21% (wt/wt) and 9.9% (wt/wt), respectively. Theoretically, media bed with a high water retention capacity could be filled/saturated with water for a much longer period and less subjected to leaching losses of nutrients. Differences in water retention capacity might be attributed to two reasons; first the degree of porosity of the material and secondly, the total organic matter of the substrate. According to our measurements (Table 1), LECA is fairly porous; recording a porosity value of 40% (v/v). Although LECA is largely made of clay, raw clay was also mixed with organic material during its production phase and thus, may improve LECA capacity in retaining a fair amount of water. Cocopeat substrates utilized in our study showed a relatively low degree of porosity i.e. about 30% (v/v). Nevertheless, Shanmugasundaram et al. (2014) reported that total organic matter in cocopeat can be as high as 89.09%. This explains why cocopeat substrates show a slightly higher water retention capacity as compared to carbonized rice husk substrates. Carbonized rice husk consisted mainly of silica and about 25.95% organic carbon (Venkatanarayanan & Rangaraju 2013). As the content of organic matter increases, the water retention capacity improves as well due to the affinity of organic matter for water. Despite a low water retention value, carbonized rice husk substrates have a highly porous structure where the degree of porosity was measured to be 65.15% (v/v). Interestingly, when cocopeat was mixed with carbonized rice husk at ratio 1:1, values for bulk density and porosity of carbonized rice husk did not change by much but its water retention capacity improves nearly double from 9.92%(v/v) to 16.33% (v/v). Obviously, in growing media mixture, increasing the volume of cocopeat would increase water retention capacity of the mixture. Similar observation was also made by Fazlil Ilahi and Ahmad (2017) where addition of cocopeat to a cocopeat-perlite substrate at ratio 3:1 have increased mixture water holding capacity.

Figure 3 presents the growth of longevity spinach plants in different substrates of our aquaponics unit over the period of twelve weeks. As expected, LECA showed excellent traits as media bed for growing of longevity spinach plants. The longevity spinach grew steadily over the period of twelve weeks recording a specific growth rate of 0.96 cm per day. LECA substrates used in each polybag provided sufficient supports for holding the plant in place whilst the air pockets between the clay pebbles offered spaces for oxygenation of roots. Additionally, capillary properties of LECA allowed water to travel several inches in upward direction to provide water to the plants for growth. Trang and Brix (2014) claims that different media bed may have different effects on nutrient uptake of plants in aquaponics system and consequently, affecting plants growth. This is however, not evident in our aquaponics unit. Comparable growth performance was observed (Figure 3) for all substrates utilized. Nitrification rates did not show any signification variation except for NO_2^- level where its reduction rates are slightly higher when using cocopeat (S3b) and carbonized rice husk (S3c) substrates as media bed (Figure 2(d)). Otherwise, over the

TABLE 1. Physical properties namely bulk density, water retention capacity and porosity of various growth media evaluated in this study. Measurements were done in triplicate samples

Substrates	Bulk density ($g\cdot cm^{-3}$)	Water retention capacity (%wt/wt)	Porosity (%v/v)
LECA	0.383 ± 0.004	36.99 ± 0.028	39.39 ± 3.5
Cocopeat	0.140 ± 0.006	21.03 ± 0.005	29.92 ± 2.6
Rice husk	0.100 ± 0.009	9.92 ± 0.088	65.15 ± 3.9
Cocopeat and rice husk mixture	0.117 ± 0.002	16.33 ± 0.100	66.67 ± 5.1

The data are expressed as mean + standard deviation period of twelve weeks, longevity spinach plants grown did not rot and chlorosis of the leaves was not seen at any of the growers. A stable pH range at slightly acidic region i.e. between pH6.5 and pH6.8 suggesting that optimal growth conditions for plant cultivation and nitrification bacteria were successfully achieved at the plant growing area.

It is believed that nutrients availability and porous structure of substrates played an important role in plant growth performance. Cocopeat are less porous and has a lower water retention capacity compared to LECA. Nevertheless, cocopeat contained a relatively rich content of macro- and micronutrients (Table 2). The amount of nitrogen, boron and sodium compounds are much higher than the ones in LECA substrates. Similarly, carbonized rice husk is enriched with high content of phosphorus, potassium, iron, and manganese as compared to LECA. Additionally, both carbonized rice husk and cocopeat-carbonized rice husk mixture have a high degree of porosity. A highly porous media bed is advantageous as it would provide adequate space for root growth and gas exchange. Roots are easily grown and spread through the porous structure to gain direct access to surrounding water for nutrient uptake and hence, improve plant yield. This

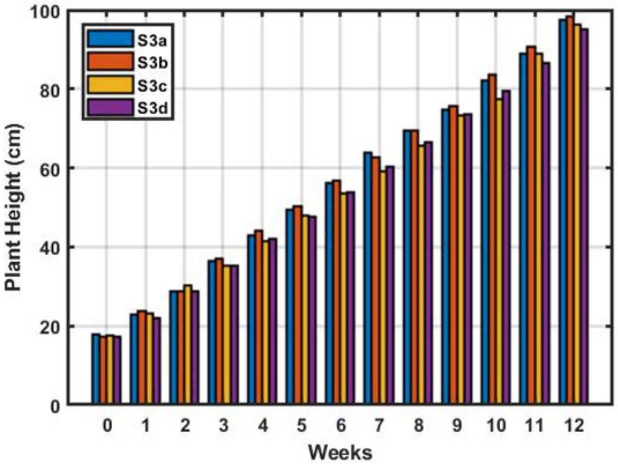

FIGURE 4. Growth of longevity spinach in terms of plant height in different substrates over the period of twelve weeks. Legends indicated types of substrates evaluated in the study which are LECA (S3a), cocopeat (S3b), carbonized rice husk (S3c) and carbonized rice husk-cocopeat mixture (S3d)

TABLE 2. Macro- and micronutrients content of various growth media evaluated in this study

Nutrients	LECA	Cocopeat	Rice husk	Cocopeat and rice husk mixture
Nitrogen, N (%w/w)	0.04	0.53	0.10	0.23
Phosphorus, P_2O_5 (%w/w)	0.003	0.05	0.45	0.52
Potassium, K_2O (%w/w)	0.09	0.12	0.44	0.28
Magnesium, Mg (%w/w)	0.07	0.10	0.15	0.06
Calcium, Ca (%w/w)	1.04	0.98	0.10	0.94
Iron, Fe ($mg \cdot L^{-1}$)	0.10	0.03	0.23	ND
Manganese, Mn ($mg \cdot L^{-1}$)	0.07	0.04	0.48	0.36
Boron, B ($mg \cdot L^{-1}$)	0.27	0.40	0.31	0.34
Molybdenum, Mo ($mg \cdot L^{-1}$)	0.07	0.09	0.09	0.08
Sodium, Na ($mg \cdot L^{-1}$)	11.33	65.6	11	11

TABLE 3. Weight gain of *Gynura procumbens* plants in the aquaponics system of this study

Growth bed media	Area of growth bed (m^2)	Total weight of *gynura* (kg/24 plants)	Harvest rate of *gynura* per area (kg/m^2)
LECA	0.2187	0.8158	3.730
Cocopeat		0.8667	3.963
Rice husk		0.8385	3.834
Cocopeat & rice husk mixture		0.7975	3.647

justified why nonconventional media bed such as cocopeat and carbonized rice husk showed a similar plant growth performance as LECA. Our hypothesis is in agreement with the report by Sikawa and Yakupitiyage (2010) which concluded that adequate air space for plants root respiration and pool of nutrients are major factors for a good plant growth.

Table 3 presents the data of the harvest rate based on weight gain of longevity spinach plants for a planting area of 0.2187 m^2. Total weight gain of longevity spinach is almost the same regardless on the types of substrate used as the growing media which is within the range of 0.8 to 0.87 kg/24 plants. Plant growing area that utilized cocopeat substrates as the media bed gave the highest harvest rate per area that is about 3.96 $kg \cdot m^{-2}$. The harvest rate recorded is comparable to some of the aquaponics system that combined Nile tilapia fish culture with basil plants production where the harvest rate varies between 0.6 $kg \cdot m^{-2}$ and 6.25 $kg \cdot m^{-2}$ - depending on the number of plants per square meter (Rakocy et al. 2006; Selek et al. 2017). It is worth mentioning that the use of polybags is very economical for plant cultivation in comparison to the classical setup for plant growing area of aquaponics unit where substrates are loaded to fill the entire area of growth bed. Operational cost can be reduced as the amount of media bed needed to achieve considerably good harvest rate is much lower with utilization of polybags. The use of polybags also prevents residues of the media bed from flowing into the sump tank which could increase the level of total suspended solids in the tank.

Conclusion

The study demonstrates the workability of a small size aquaponics unit (4.5 m^2) for cultivating Red Nile tilapia fish and growing of *Gynura procumbens* in equatorial climate conditions. Four different type of media bed namely LECA, cocopeat, carbonized rice husk and carbonized rice husk-cocopeat mixture were utilized as media bed for cultivation of longevity spinach plants. Water quality analysis over the period of twelve weeks showed that temperature, pH, DO level, and TSS of the aquaponics system were all within acceptable limits and suitable for the growth of Red Nile tilapia, longevity spinach and the nitrification bacteria. Microbial population was fully developed and ensured a reasonable level of ammonia, nitrites and nitrates. No sign of nutrient deficiencies was observed and a healthy longevity spinach growth was achieved for all four substrates evaluated in this study. Based on the results attained, it can be concluded that cocopeat and carbonized rice husk substrates are suitable alternative to be utilized as media bed for aquaponics unit.

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Muhd Nazrul Hisham Zainal Alam & Sani Amril Samsudin
Department of Bioprocess and Polymer Engineering
School of Chemical and Energy Engineering
Faculty of Engineering
Universiti Teknologi Malaysia
81310 Johor Bahru, Johor Darul Takzim
Malaysia

Nur Syahmi Izzati Ali Othman, Anwar Johari, Mimi Haryani Hassim & Mohd Johari Kamaruddin*
Department of Chemical Engineering
School of Chemical and Energy Engineering
Faculty of Engineering
Universiti Teknologi Malaysia
81310 Johor Bahru, Johor Darul Takzim
Malaysia

Anwar Johari, Mimi Haryani Hassim & Mohd Johari Kamaruddin*
Centre of Hydrogen Energy (CHE)
Institute of Future Energy
Universiti Teknologi Malaysia
81310 Johor Bahru, Johor Darul Takzim
Malaysia

*Corresponding author; email: mjohari@utm.my

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