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Growth Performance of Tomato Plant and Genetically Improved Farmed Tilapia in Combined Aquaponic Systems

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ABSTRACT

Aquaponic system is an integration of aquaculture and hydroponics in a closed aquaculture system. Plants are able to grow without the presence of soil using natural fertilizer available in the system as a result of nutrients produced from nitrification process by the nitrifying bacteria. The aim of this study is to evaluate the growth performances of Genetically Improved Farmed Tilapia (GIFT) and tomato plant (*Solanum lycopersicum*) in a combined aquaponic system. This system is a mix of Deep Water Raft System (DWRS) using a styrofoam base with a small hole made for plant to float placed in a small pot filled with gravel used to support the plants and Media Filled System (MFS) applying a plant tank fully filled with gravel as media for the plant to grow. This study was conducted to determine whether combined aquaponic system could improve the effectiveness of the plant growth. GIFT gained 94% of body weight and tomato increased 96.3% in terms of plants height and started flowering (the early stage of fruit formation). Besides, the range in concentration of TAN (0.29±0.4 mg L^{-1}), nitrite (0.65±0.59 mg L^{-1}), nitrate (1.29±1.29 mg L^{-1}) and phosphate (0.57±0.1 mg L^{-1}) recorded in the culture system are suitable for facilitating the nitrification process. Analysis of the data proves that the combined aquaponic system is more effective than the single DWRS aquaponic system.

Key words: Aquaculture, aquaponic system, fish growth, tomato flowering

INTRODUCTION

Aquaponic is a combined culture of aquatic animals and land plants (especially vegetables) in a closed aquaculture system (Rakocy *et al.*, 2006). Interest in this method of integrated culture is rapidly catching up due to production efficiency and operation of the system on biodynamic principles that reduce the demand on externalities (Estim and Mustafa, 2010, 2011). Nutrients leaching from the uneaten feed and metabolic waste of aquatic animals dissolve in the water and modulate the chemical composition of the medium. This nutrient-rich water contains ammonia (NH_3), nitrite (NH_2^-), nitrate (NH_3^-) and phosphate (PO_3^-). The process of nitrification that ensues in the culture medium provides food and fertilizers for the plants. The plant acts as a biological filter to absorb harmless nutrients (nitrate, NH_3^-) from the water. Finally, the filtered water flows back and is re-used in the fish tank. Nutrient removal by the plants improves the water quality in the system, balances the pH, maintains Dissolve Oxygen (DO) and enhances the production of cultured aquatic animals (Endut *et al*., 2010).

The combination of cultured aquatic animals and plants has been studied for more than 30 years involving a range of aquaponic designs, diversity of aquatic animals and plants as well as different experimental protocols (Seawright *et al*., 1998). It has inspired the researcher and aquaculturist to design many varieties of aquaponic systems available in the market.

The choice of hydroponic growing system within an aquaponics context is based on the advantages that accrue from integration of fish with vegetables in the system (Lennard and Leonard, 2006). Growing plants in the soil demands substantial amounts of nutrients and expensive biosecurity measures and when cultivation involves high density of plants, the competition for nutrients constraints growth. The waste water from fish tanks is not just that it is cost-free, but also supplies nutrients in which contains all the essential elements. If not used in production module, the same wastewater will cause environmental degradation. Plants in hydroponics and aquaponics grow more rapidly compared to their counterparts which grow in the soil because the root system is in direct contact with nutrients and nutrient uptake is more efficient in an aqueous phase (Azad *et al*., 2013). Probably, nutrient uptake from water consumes less energy than extraction of nutrients from soil and thereby allowing more energy to be utilized in growth of biomass. The aquaponic systems involved in this research were Media Filled System (MFS): A system that uses gravel beds to grow plants and at the same time serves biological filtration in the system and Deep Water Raft System (DWRS) which is essentially a hydroponic subsystem that used styrofoam to float the plants put into small pots filled with gravel for mechanical support.

Each of these systems has pro and cons. MFS improvised the system with mechanical and biological filters besides serving to increase the surface area for the nitrifying bacteria. Obviously, the conversion of nutrients (ammonia to nitrite finally to nitrate occurred) occurs more effectively. However, this medium is heavier and more man power is needed to clean up the system, especially the gravel beds. The DWRS is easily to install and manage as it only requires styrofoam with small holes on it to put the small pot for the plants but chances disease are high due to the reason that all the roots are fully submerged in the water.

Because, aquaponics is a new research area, there is a paucity of scientific data for comparisons. This experiment was conducted to test whether the combined aquaponic system (MFS and DWRS) is better and more effective compared to single DWRS in aquaculture system through rigorous monitoring of water quality changes and the growth and survival rate of fish and tomato plants.

MATERIALS AND METHODS

Aquatic animal and plant: Specimens of genetically improved farmed Tilapia obtained from Ko-Nelayan Hatcery were selected for the trials. The fish were held outdoors and reared in 10 t spherical tanks in a closed recirculating system before transfer to the experimental tank. The specimens ranged 10-30 g in body weight. Stocking density was 50 fish m^{-3}. Tomato (*Solanum lycopersicum*) plant was chosen as the target fruiting vegetable for this experiment.

Aquaponic system description: The experimental infrastructure consisted of 6 individual systems divided into two treatments. Treatment 1 was the combination of MFS and DWRS in one

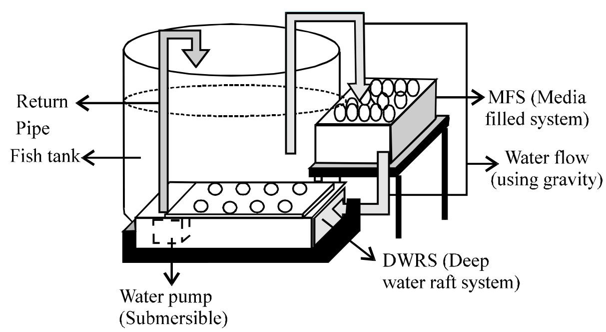

Fig. 1: Combined MFS and DWRS in a closed recirculating aquaculture system

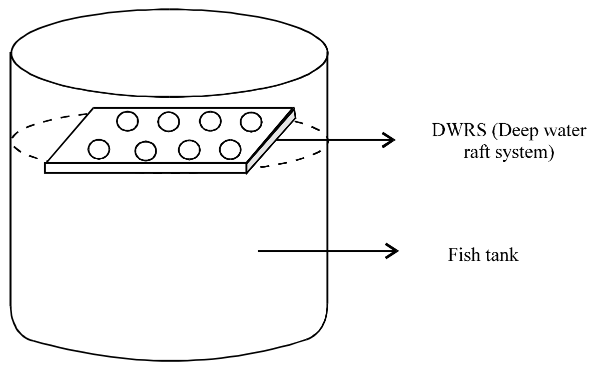

Fig. 2: Single DWRS in fish tank

closed recirculating system (Fig. 1). This combined MFS and DWRS system used round fish tank (1000 L) and two plant tanks (approximately 70 L) as hydroponic subsystem in the form of: Media filled system (using washed gravel as the media) and deep water raft system (using styrofoam to float the pot of plants).

The effluent from fish tank flowed under gravity into MFS that was filled with gravel. The water level in the fish tank was maintained higher than the MFS tank to allow this flow. After filtration in MFS, the water released for flow into the DWRS at the lowest point in the system. There was a single submersible water pump (15 W) for lifting approximately 500 L of water per hour in the DWRS tank and this water was pumped back to the fish tank and this cycle was continued. The tomato plants were put in each of the hydroponic subsystems (MFS and DWRS) one week after stocking of the fish in the experimental unit.

The other treatment comprised only single DWRS closed static water system. It only consisted of round fish tank (1000 L) and floating DWRS inside the fish tank (Fig. 2). Water used in these trials originated from the tap water and was potable quality. The water was exposed to strong aeration at least once before water being used to remove possible traces of chlorine which are known to be harmful for the fish.

Experimental methodology: The experiment was conducted at the hatchery of Pusat Pembenihan Ikan dan Udang Ko-Nelayan, Kg. Laya-Laya, Tuaran, Sabah. All the tanks were put beneath a transparent roof with an additional of black cover nets for shade that curtailed almost for 50% of the radiations. The fish were fed with commercial pellet (25% of protein) twice per day in the morning and late afternoon. Two separate treatments, each with three replicates involved were:

- **Combined aquaponic system:** Deep Water Raft System (DWRS) using styrofoam to keep the plants afloat while they are placed in small pots filled with gravel to provide mechanical support and Media Filled System (MFS) that used gravel for plant beds
- **Single aquaponic system:** Only Deep Water Raft System (DWRS) that used styrofoam to float the plants placed into small pots filled with gravel

Data collection: Observations on fish and plant were made every two weeks over a period of three months to assess their growth performance. The data included body weight gain (g), specific growth rate (SGR), survival rate of fish (%), dry feed intake (g) and also the feed conversion ratio. Following equations were used:

$$\text{Body weight gain (BWG)} = \frac{W_2 - W_1}{W_1} \times 100$$

$$\text{Specific growth rate (SGR)} = \frac{\ln W_1 - \ln W_0}{T_1} \times 100$$

$$\text{Survival rate (\%)} = \frac{\text{No. of fish at the end of experiment}}{\text{No. of fish at the starting time of experiment}}$$

$$\text{Feed conversion ratio (FCR)} = \frac{\text{Dry weight of feed given (g)}}{\text{Weight gain (g)}}$$

Where:
W_1 = Initial mean weight (g)
W_2 = Final mean weight (g)
T_1 = Duration of experiment (days)
ln = Natural log

As for the growth of plants:

$$\text{Height of plants} = \text{Final height of plants} - \text{Initial height of plants}$$

$$\text{Growth rate} = \frac{\text{Height of plants (cm)}}{\text{Culture period (days)}}$$

Plant growth was monitored by measuring the height of all the tomato plants in each of the hydroponic sub-systems and counting the number of shoots and flowers (representing the early stages of fruiting).

Water quality samples analyses: The water quality parameters considered in the experiment were *ex-situ* and *in-situ* parameters. Physico-chemical parameters collected were ammonia (NH_4), nitrite (NH_2), nitrate (NH_3^-) and phosphate (PO_3^{-4}). Water sampling was done once per week. Water samples were refrigerated at 4°C in labelled polyethylene bags and analyzed using calorimetric method (Wetzel and Likens, 2000). The *in-situ* parameters including Dissolved Oxygen (DO), pH and temperature (°C) collected once in two days in morning (09:00) and evening (16:00) by using multi-parameter meter HANNA (HI 9828).

Data analysis: All the data collected was analyzed to calculate the mean and standard error by using Microsoft Excel 2010 and SPSS 18.0 (statistical package for Social Sciences).

Data on growth and survival rates of fish and plants was analyzed using one-way ANOVA. The values were compared by using the Shapiro-Wilk test, followed the homogeneity test and finally Tukey HSD test to evaluate statistical differences.

RESULTS AND DISCUSSION

GIFT: The survival rate of GIFT was 100% in all replicates (for each of the treatment) in the 60 days of experimental trial. Specific growth rates of GIFT in all the treatments did not differ significantly ($p>0.05$) and similar results (lack of significant difference) were obtained for the Feed Conversion Ratio (FCR) (Table 1). It is evident from the data that the growth performance of the fish was not affected by the culture based on the aquaponic system.

In an aquaculture system, fish growth performance is vitally important and any supplementary food crop that grows well in integrated system provides additional revenue and contributes to economic feasibility of high-value aquatic food production (Lennard and Leonard, 2006). Thus, in the present study, the survival rate of GIFT was 100% and showed no diminution of growth of the fish.

Tomato (*Solanum lycopersicum*): The growth rate of tomato in the experiment was within the range of values reported by Rana *et al.* (2011). These authors stated faster growth of the plant in a closed recirculating aquaculture system. However, in our experiment there was no significant difference in the tomato grown under the two different conditions. Nevertheless, the results suggested that tomato plant is well suited for aquaponic system, using nutrients from fish tank serving as fertilizers. The results were better from the combined MFS and DWRS compared to single DRWS. The plants on single DRWS had low survival rate (57%) compared to the plants in the combined DWRS and MFS, with 95% survival and increase to the tune of 96.3% in terms of plant height, early flowering and fruiting (Fig. 3b and c). In the single DWRS, most of the tomato leaves wilted and only a few newly shoot observed in the system (Fig. 3a).

Table 1: Evaluation growth performances of GIFT

Parameter	Combined MFS and DWRS	Single DWRS
Weight gain (yield, kg)	1.19 ± 7.49^a	1.04 ± 8.50^a
SGR	1.5 ± 0.13^a	1.3 ± 0.06^a
FCR	2.0 ± 0.08^a	2.2 ± 0.12^a
Dry feed intake (yield, kg)	2.5	2.5

All values are in Mean±SE, same letters indicate no significant difference ($p>0.05$) while different letters show significant differences ($p<0.05$)

Fig. 3(a-c): Condition of plant in (a) Single DWRS and (b, c) Combined aquaponic system

Table 2: Concentration of TAN, nitrite, nitrate and phosphate in the combined and single DWRS aquaponic system

	Concentration (mg L^{-1})		
Parameters	Initial reading	Intermediate reading	Final reading
Combined system			
Ammonia (NH_3-N)	0.35	0.29	0.23
Nitrite (NO_2-N)	1.50	0.26	0.20
Nitrate (NO_3-N)	2.40	0.80	0.68
Phosphate (PO_4^-)	0.70	0.52	0.48
Single DWRS			
Ammonia (NH_3-N)	0.50	0.20	0.18
Nitrite (NO_2-N)	0.90	1.00	0.80
Nitrate (NO_3-N)	2.23	1.72	1.51
Phosphate (PO_4^-)	0.75	0.63	0.66

Water quality parameters: In the combined system, the concentration of TAN, nitrite, nitrate and phosphate reduced with the period of cultured in all the systems (Table 2). The pattern of nitrification process can be observed with higher concentration of nitrite in the beginning for the first half of the experiment and finally decreased with the lapse of time because of the conversion of nutrient involved in nitrification process and finally, the end nutrient produced was nitrate (NO_3^-) which is absorb and used by the plants as food and natural fertilizer needed for them to grow (Fig. 4). For single DWRS, the nitrification process is less effective as in the combined system because fluctuation of nutrient did not decrease with time. The results showed that the tomato did not grow as well as in the combined system (Fig. 5). This may be due to static water in the tanks and without the presence of filtration system and inadequate conversion of nutrients than in the combined system. Moreover, some root tissues of the plants in single DWRS may have been eaten by the fish because of their direct contact. Probably, this also caused the plants in single DWRS to be affected by pathogen or stress factors which resulted in stunted growth.

Biological nutrient removal was possible due to the unique characteristics of certain plants grown hydroponically which can transfer the atmospheric oxygen through their root system and provide substrate for the attachment of microbial communities, which is an important role of plants in aquaponic systems (Endut *et al*., 2011). This is the reason for hydroponic plants (especially green

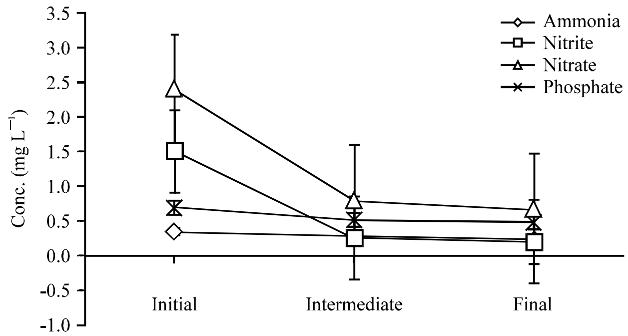

Fig. 4: Concentration of ammonia, nitrite, nitrate and phosphate in the combined MFS and DWRS in closed recirculating water system

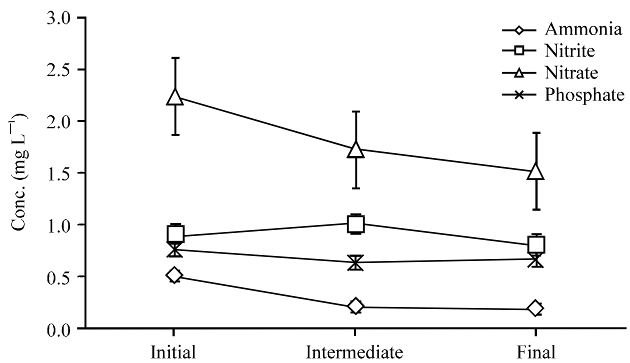

Fig. 5: Concentration of ammonia, nitrite, nitrate and phosphate in the single DWRS in static water

Table 3: Range of dissolved oxygen, pH and water temperature during the period of the experiment

Parameters	Combined system	Single system
Dissolved oxygen (mg L^{-1})	5.92-7.10	5.43-7.58
pH	7.79-7.50	7.80-7.00
Temperature (°C)	26.60-30.81	26.12-28.91

leafy and fruiting vegetables) which have elongated roots. The association of microbial communities in the roots and filtration system were helpful in effective of breakdown of certain components involved in the aquaponic system, for example, oxidation of ammonia to nitrite and finally nitrate (nitrification process).

Moreover, study conducted by Eding and Kamstra (2001), stated that recommended concentration of nitrite (NO_2^-) in culture system was less than 0.15 mg L^{-1} and this value was approximately the same as obtained in the present study (Table 3). The concentration of phosphate in the final reading showed a declining trend throughout the period. This could be linked to the functioning of roots which were fully developed and had the ability to absorb phosphate produced in the system (Endut *et al*., 2009). Ebeling *et al*. (2006) stated that most of the discharged phosphorus from the aquaculture system, accumulates in the sedimentation segments. It often becomes a limiting factor in natural ecosystems and the excessive release of phosphorus can lead to blooming of algae in the environment.

Dissolved oxygen, pH and water temperature: Table 2 shows the range of Dissolved Oxygen (DO), pH and water temperature (°C) during the course of experiment. These are among the most important parameters requiring regular monitoring because their profiles reflect the condition of aquatic organisms in the culture system. Based on the results, the aquatic organisms involved in this experiment were in a good condition except for the growth of plants in single DWRS system.

Poor water quality will cause the death of the plant crop and the loss of investment (Wurts, 2005). Moreover, the water parameters showed no significant differences during the culture period and were within the suggested range for prawn culture.

CONCLUSION

The combined aquaponic system did not adversely affect the growth the captive stock of GIFT. Growth of the tomato plant differed when stocked in single and combined aquaponic system, depending upon the nutrient variability. Dynamics of the nutrients in the culture medium was modulated by the nitrification process and general conditions inside the system. Water quality parameters varied due to disparity in nutrient conversion and rate of their uptake by the plants. The outcome from this research is useful for farmers who can implement the system in fish farms, tanks or ponds for creating business opportunities while widening the market for organic plants (vegetables). The combined aquaponic system is better than the single aquaponic system in terms of growth performance of tomato. A great deal of research will be required to generate more information of the profitability of the aquaponic system.

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