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A study on the optimal tank design and feed type to the growth of marble goby (*Oxyeleotris marmorata* Bleeker) and reduction of waste in a recirculating aquaponic system

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ABSTRACT

Marble goby (*Oxyeleotris marmorata* Bleeker), a profitable aquaculture species, was cultured in partitioned tanks treated with a water recirculating aquaponic system (RAS). The influence of tank design (with partitions and PVC tubes of different sizes) and feed type (live food and minced fish) on the fish growth and waste production was investigated. The fish cultured in big partitions with PVC tubes showed higher growth (2.5 g/d) and feed intake (468 g/d) than other tank designs (growth: $\leqslant$2.2 g/d; feed intake: $\leqslant$433 g/d). The growth of fish fed with live tilapia (*Oreochromis niloticus*) (2.5 g/d) was significantly higher than that of fish fed with live carp (*Cyprinus carpio*) (1.9 g/d) and minced scads (*Decapterus russellii*) (1.6 g/d). Fish fed with minced scads showed the highest waste production (ammonia nitrogen (TAN): 262 mg/kg d; 5-d biochemical oxygen demand (BOD_5): 434 mg DO/kg d; total suspended solid (TSS): 2.1 g/kg d) compared to those fed with live food (tilapia and carp) (TAN: $\leqslant$208 mg/kg d; BOD_5: $\leqslant$344 mg DO/kg d; TSS: $\leqslant$1.9 g/kg d). Live food, particularly tilapia, was found to be the preferential diet for marble goby as indicated by the highest fish growth (2.5 g/d) and feed utilization (feed conversion efficiency (FCE): 0.46), and the lowest waste production (TAN: 140 mg/kg d; BOD_5: 232 mg DO/kg d; TSS: 1.4 g/kg d) compared to that of fish fed with minced fish (growth: $\leqslant$1.6 g/d; FCE: $\leqslant$0.31; TAN: $\geqslant$198 mg/kg d; BOD_5: $\geqslant$328 mg DO/kg d; TSS: $\geqslant$1.9 g/kg d). Our results also indicate that the use of culture tank with big partitions and PVC tubes coupled with a RAS show exceptional promise as a means to the reduction of waste by marble goby fed with live tilapia (TAN: $\leqslant$140 mg/kg d; BOD_5: $\leqslant$232 mg DO/kg d; TSS: $\leqslant$1.8 g/kg d) and in turn providing a good water quality environment for the culture of the fish.

Keywords: Aquaculture; Waste; Aquaponic; Tank design; Feed

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1. Introduction

Marble goby (*Oxyeleotris marmorata* Bleeker), commonly known to the Southeast Asians as "Ketutu" or "Soon Hock", is a good eating freshwater fish. It commands a high price with its market value in Malaysia ranging from a wholesale price of RM60/kg to RM86/kg [1–3]. Owing to its high market value, it is regarded as a potential profitable aquaculture species in Malaysia, and vigorous efforts have been made to perfect the techniques for the culture of this fish. Marble goby is conventionally cultured in cages in reservoirs, lakes, and rivers, and also in ponds in several Southeast Asian countries such as Malaysia, Thailand, and Vietnam [2–4].

Despite the use of various conventional methods to culture the fish, there are still problems exist at present in the conventional culture of marble goby [5,6]. Some initial attempts to culture the fish in earthen ponds and cages in Thailand and Vietnam failed, because of its slow growth during juvenile stage, high mortality rate, peculiar feeding behavior, and lack of formulated feeds [7–9]. Furthermore, the inherent cannibalistic and territorial behaviors of the fish further reduce its production in cage and pond culture. These problems are thought to be related to the poor water quality and lack of appropriate control present in the conventional culture of marble goby. As a result, the fish is highly stressed and becomes easily disease-infected [5], leading to slow growth and increased mortality of the fish. It is thus important to find an alternate culture technique to rectify these deficiencies in order to ensure better control of the culture method as well as the production of the fish.

Recirculating aquaponic system (RAS) can potentially be a good alternative solution to fish culture as it ensures a good controlled culture conditions by providing a better control of the water quality and prevention of fish disease [10,11]. These can potentially lead to higher survival and faster growth of the fish and thus enhancing the production of this fish [12]. RAS also allows for intensive culture with reduced or limited waste discharge, thereby reducing the use of land and water resources and also minimizing adverse environmental impacts [13–15].

Owing to the tremendous market demand for marble goby and the limitations and poor fish yield shown by conventional culture methods, it was thought useful to investigate the possible development of a water RAS for efficient control of water quality and improved fish production from the culture of the fish. The distinct advantages shown by RAS may overcome the poor growth and disease problem shown by conventional cage and pond culture systems and lead to the potential for the greater production of the fish.

So far, limited information is available on the characteristics of the culture of marble goby by RAS. Studies on the application of RAS have been reported in the culture of other species, such as seabass [16], African catfish [12], and carp [17]; however, no similar studies have been reported on marble goby. This study investigates the influence of tank design (with partitions and PVC tubes of different sizes) and feed type (live food and minced fish) on the growth and waste production by the fish cultured in a RAS, with a focus on the ammonia nitrogen (TAN), total nitrogen (TN), 5-d biochemical oxygen demand (BOD_5), and total suspended solid (TSS) generated by the fish. The fish were individually cultured in partitioned tank with PVC tubes in order to evaluate the feasibility of this approach in overcoming their cannibalistic and territorial behaviors. Live food was selected for this study due to its ease of acquisition, and the fact that marble goby is a passive carnivorous fish and there is virtually no suitable artificial feed for the fish. These evaluations are important to assess the technical feasibility of the tank design, the diets, and the RAS as an alternative method for the culture of the fish.

2. Experimental section

2.1. Fish and acclimation

Marble goby with a body weight of approximately 100 g was obtained from various local sources. Before experiments, the fishes were acclimated individually in 195 L fiberglass rectangular holding tanks supplied with a continuous flow of well-aerated fresh water (water temperature: 27.5 ± 0.5°C; pH: 7.5 ± 0.5; dissolved oxygen (DO) >6 mg/L). The water was passed through a UV disinfection unit before being supplied to the holding tanks in order to ensure the water is disease free. During acclimation, the fish were fed to satiation once a day with live tilapia (*Oreochromis niloticus*).

2.2. Experimental design of RAS

The RAS developed and used for this investigation is shown in Fig. 1. It consists of a fish culture tank, a filter floss unit, a degassing unit, a biofilter unit, a hydroponic unit, a denitrification unit, and a reservoir sump. Glass aquaria and fiberglass rectangular tank were used for the culture of marble goby. Air stones connected to an air blower were diffusely placed into the culture tank in order to maintain sufficient oxygen

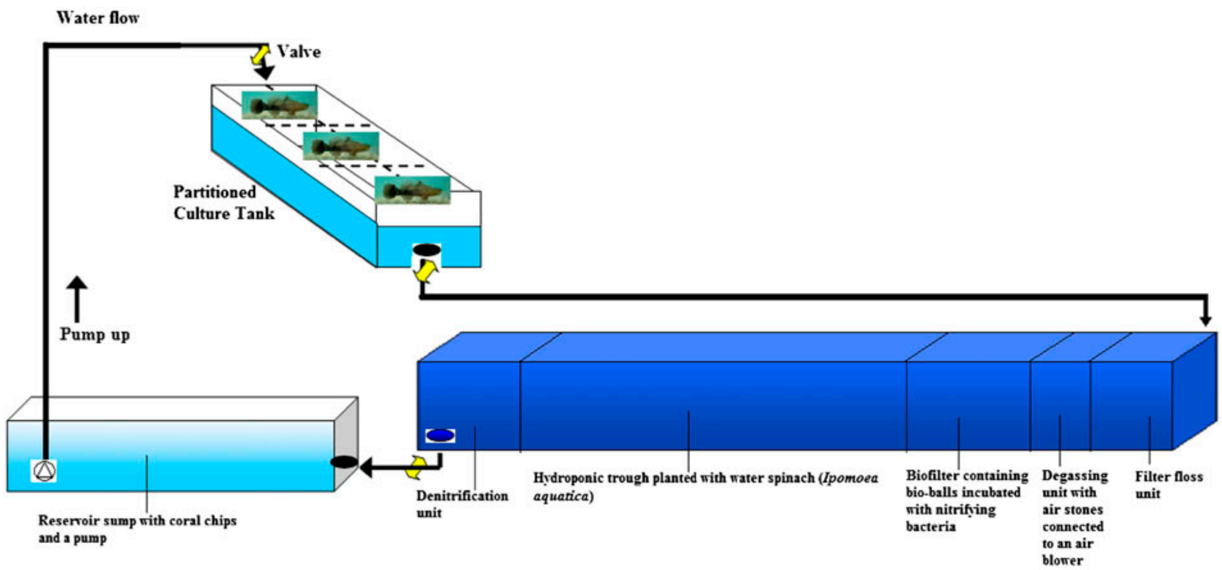

Fig. 1. Schematic layout of water RAS.

supply to the fish. Effluent from the fish culture tanks is first treated by a filter unit, which is filled with filter floss or filter mats of different thicknesses for solid removal. Then, a degassing unit filled with air stones connected to an air blower is used to vent any undesired gases (e.g., H_2S) produced in the effluent from the filter unit. Next, the effluent is treated by a trickling biofiltration unit installed with bioballs incubated with nitrifying bacteria, which removes the ammonia excreted by the fish by oxidizing the ammonia to nitrate by nitrification. The effluent then flows through an aerated hydroponic trough (0.5 m^2 area, 0.6 m height) grown with hydroponic plant (water spinach, *Ipomoea aquatica*) where nitrate is absorbed and recovered by the plant as nutrient. Water spinach was planted on polystyrene sheets that floated along the hydroponic trough; the polystyrene sheet supported the plants at the water surface with roots suspended in the culture water, providing good exposure of the roots to the culture water while preventing undesired clogging. This is followed by the use of a well-sealed denitrification unit incubated with denitrifying bacteria in order to convert the remaining nitrate in the effluent to nitrogen gas under anaerobic condition. Finally, the effluent is channeled into a reservoir sump filled with crushed coral, which serves as a buffering substrate to maintain a pH of 7.5 ± 0.5 in the RAS system. The treated water is then returned to the fish culture tank through the use of a pump. PVC pipelines were used to circulate water between the culture tank and the RAS units. Water exchange was timed to ensure that the maximum level of TAN for fish culture (3 mg TAN/L) was not exceeded [18].

2.3. *Experimental details on the influence of tank design and feed type*

2.3.1. *Design of culture tank*

Five designs of culture tank were set up and tested, namely:

(1) *Big-P*—three 195 L glass aquaria culture tanks with each culture tank containing 8 big space plastic partitions, amounting to a total of 24 partitions (Fig. 2).
(2) *Small-P*—three 195 L fiberglass rectangular culture tanks with each culture tank containing 12 narrow space net partitions, amounting to a total of 36 partitions (Fig. 3).
(3) *Non-P*—three 195 L fiberglass rectangular culture tanks without partition; tank dimension:

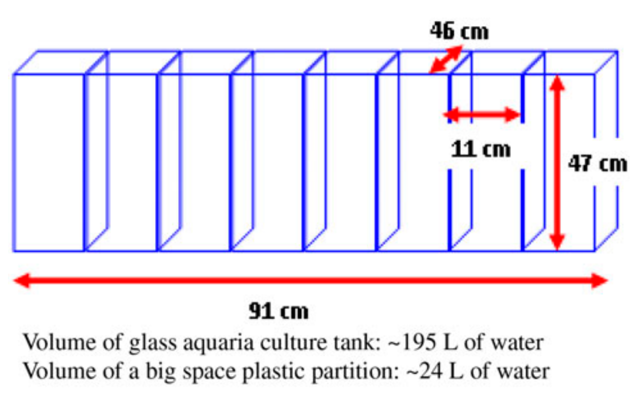

Fig. 2. Schematic layout of the glass aquaria culture tank and the big space plastic partitions.

length = 100 cm, width = 65 cm, height of water = 30 cm, volume = 195 L of water.

(4) *Big-P tubes*—three 195 L glass aquaria culture tanks with each culture tank containing 8 big space plastic partitions and 8 PVC tubes (50 mm diameter), amounting to a total of 24 partitions with PVC tubes; the dimension and layout of the glass aquaria culture tank and the big space plastic partitions is similar to that used in Big-P (Fig. 2), except with the addition of PVC tubes into the partitions as illustrated in Fig. 4.

(5) *Non-P tubes*—three 195 L fiberglass rectangular culture tanks without partition but with 8 PVC tubes (50 mm diameter) in each culture tank; tank dimension: length = 100 cm, width = 65 cm, height of water = 30 cm, volume = 195 L of water.

2.3.2. Type of feed

Three types of feed were selected for this study, namely:

D1: Live tilapia (*Oreochromis niloticus*); size per fish: 3 ± 1 cm in total length, weight: 4 ± 1 g

D2: Live common carp (*Cyprinus carpio*); size per fish: 3 ± 1 cm in total length, weight: 4 ± 1 g

D3: Minced scads (*Decapterus russellii*); size per slice: thumb-sized in 4 ± 1 g

The selected feeds were analyzed for crude protein, crude fat, ash, and fiber content according to AOAC [19], and these were presented in Table 1. The live feed (tilapia and carp) was disinfected through UV and pulsed-UV procedures in order to eliminate any attached pathogens before being fed to the marble goby, ensuring that the live feed is disease free.

Fig. 4. Partitioned culture tanks with PVC tubes.

2.3.3. Experimental procedure

The experiment was conducted in culture tanks treated by RAS (see Section 2.2) with the water temperature maintained at 27.5 ± 0.5℃, pH controlled at 7.5 ± 0.5, and the level of DO monitored at >6 mg/L. The experimental culture tanks were subjected to natural 24 h light/dark cycle (i.e., 12 h of light photoperiod/12 h of dark photoperiod).

The first variable to be studied was the tank design. Hundred and twenty pieces of marble goby (100 ± 5 g) were placed in 15 culture tanks of different designs (i.e., Big-P, Small-P, Non-P, Big-P tubes, Non-P tubes; see Section 2.3.1), with 3 culture tanks and 24 fishes being allocated for each tank design,

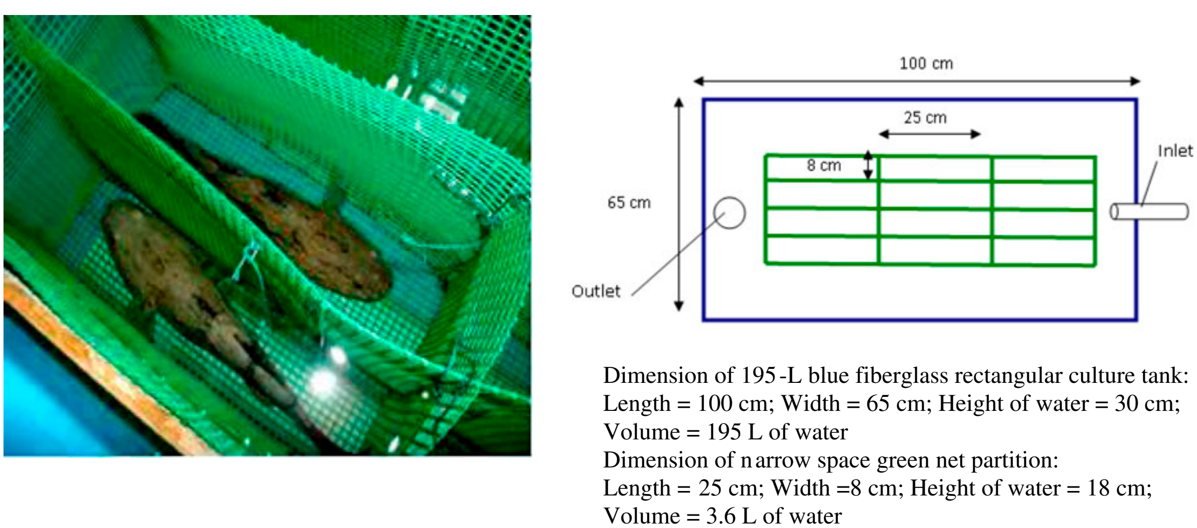

Fig. 3. Schematic layout (right) and photo (left) of the fiberglass rectangular culture tank with the narrow space net partitions.

Table 1
Composition of experimental feeds

	Diet		
	Live tilapia	Live carp	Minced scads
Proximate composition (as fed basis)[a]			
Moisture	76.4 ± 0.5	80.2 ± 0.6	79.4 ± 0.6
Crude protein	15.6 ± 0.1	15.1 ± 0.2	14.8 ± 0.1
Crude fat	3.8 ± 0.1	3.2 ± 0.1	4.5 ± 0.1
Ash	3.8 ± 0.1	1.3 ± 0.1	1.0 ± 0.1

[a]Means of three biological replicates.

and each of the culture tank contained 8 fishes, respectively (i.e. number of treatment replicate for each tank design = 3, sample size for each treatment replicate = 8 fishes). In particular, the fishes were placed individually into each partition for the partitioned tank (Big-P, Small-P, Big-P tubes). Prior to experimentation, the fishes were acclimated to the culture tank conditions and fed to satiation once a day with live tilapia for two weeks. Seedlings of water spinach were planted directly into the polystyrene sheets that floated along the hydroponic trough (Fig. 1; See Section 2.2). Then, the experiments commenced by investigating the growth and waste production by the fishes cultured in tanks of different designs for 12 weeks. During the 12 week experimental period, the fishes were fed once a day to satiation (equivalent to a feeding rate of about 5% body weight/d) with live tilapia. The feed consumption and fish mortality were recorded daily. Water samples were collected from both the inlet and outlet of each culture tank at a daily interval for determination of the water quality and the waste production in the culture tanks. The sampling was performed at around 9 am daily, and the water samples were then transferred into glass bottles and stored at 4˚C until further analysis. At the end of the 12 week experimental period, the fishes in each tank were collected and subjected to different growth measurements.

Following the investigation of the influence of tank design, study was performed to examine the feed type (Section 2.3.2) as another variable in order to understand the influence of this variable on the growth and waste production by the marble goby cultured in the RAS. The experimental design developed for this investigation is similar to that described in the study of tank design as previously mentioned. The only change from this description is the use of live common carp and minced scads to replace live tilapia as the feed to the marble goby (i.e., number of treatment replicate for each feed type = 3, sample size for each treatment replicate = 8 fishes). Following the experiments on the influence of tank design with the use of live tilapia as the feed to the marble goby, the same experimental procedure was repeated with live common carp as the feed to the marble goby. Then, the same experimental procedure was again repeated with minced scads as the feed to the marble goby, and all these results were compared to the experiments performed on marble goby fed with live tilapia and live common carp.

2.3.4. Growth measurement

At the end of the experimental period, fish in each culture tank was individually weighed after anesthetizing with 2-phenoxyethanol at 0.5 ml/L of water. Three fishes from each culture tank were randomly collected and frozen. The samples were later dried at 60˚C, ground, and analyzed for proximate composition according to AOAC [19]. Data on initial weight, final weight, feed intake, and proximate composition of diets and carcass were used to calculate the specific growth rate (SGR), absolute growth rate (AGR), feed conversion efficiency (FCE), protein efficiency ratio (PER), and productive protein value (PPV). These were calculated as follows:

$$\%\,\mathrm{SGR}\,(\%\,d^{-1}) = [(\ln W_2 - \ln W_1)/(T_2 - T_1)] \times 100 \quad (1)$$

$$\mathrm{AGR} = (W_2 - W_1)/T_2 - T_1 \quad (2)$$

where

W_1 = Initial wet body weight of fish (g) W_2 = Final wet body weight of fish (g) $T_2 - T_1$ = Length of culture period, d (d)

$$\text{Feed conversion efficiency}(FCE) = \text{Weight gain(g)/Feed intake(g)} \quad (3)$$

$$\text{Protein efficiency ratio(PER)} = \text{Weight gain}(g)/\text{Protein intake}(g) \quad (4)$$

$$\text{Productive protein value (PPV)} = (\text{Protein gain}(g)/\text{Protein intake(g)}) \times 100 \quad (5)$$

2.3.5. Measurement of water quality and waste production

Water samples were collected from the culture tanks and analyzed for TAN, TN, BOD_5, and TSS for determination of the water quality and the waste production by the fish in the culture tanks. The level of

Table 2
Growth and survival of marble goby in relation to different tank designs and diets

Diet: Tank design	Initial weight (g/fish)	Final weight (g/fish)	AGR[1] (g/d)	SGR[2] (%/d)	Survival (%)
Tilapia					
Big-P tubes	101 ± 2	314 ± 9^{a}	2.5 ± 0.1^{a}	1.3 ± 0.04^{a}	100^{a}
Big-P	101 ± 2	285 ± 8^{b}	2.2 ± 0.1^{b}	1.2 ± 0.04^{b}	100^{a}
Non-P tubes	100 ± 1	251 ± 5^{d}	1.8 ± 0.1^{d}	1.1 ± 0.02^{d}	75^{b}
Non-P	100 ± 1	247 ± 5^{d}	1.7 ± 0.1^{d}	1.1 ± 0.02^{d}	63^{c}
Small-P	100 ± 3	173 ± 7^{j}	0.9 ± 0.1^{i}	0.7 ± 0.03^{i}	100^{a}
Carp					
Big-P tubes	101 ± 1	260 ± 7^{c}	1.9 ± 0.1^{c}	1.1 ± 0.03^{c}	100^{a}
Big-P	100 ± 1	248 ± 5^{d}	1.7 ± 0.1^{d}	1.0 ± 0.02^{d}	100^{a}
Non-P tubes	100 ± 1	231 ± 6^{ef}	1.5 ± 0.1^{ef}	1.0 ± 0.03^{ef}	75^{b}
Non-P	100 ± 1	221 ± 4^{g}	1.4 ± 0.1^{g}	0.9 ± 0.02^{g}	63^{c}
Small-P	100 ± 1	163 ± 5^{k}	0.7 ± 0.1^{j}	0.6 ± 0.03^{j}	100^{a}
Scads					
Big-P tubes	100 ± 1	236 ± 5^{e}	1.6 ± 0.1^{e}	1.0 ± 0.03^{e}	100^{a}
Big-P	100 ± 1	227 ± 3^{f}	1.5 ± 0.0^{f}	1.0 ± 0.02^{f}	100^{a}
Non-P tubes	101 ± 1	208 ± 4^{h}	1.3 ± 0.1^{h}	0.9 ± 0.03^{h}	63^{c}
Non-P	100 ± 1	202 ± 4^{i}	1.2 ± 0.0^{h}	0.8 ± 0.02^{h}	63^{c}
Small-P	100 ± 1	153 ± 3^{l}	0.6 ± 0.0^{k}	0.5 ± 0.03^{k}	100^{a}

Values are mean ± SD ($N = 3$) and means with the same superscript in the same column are not statistical different ($p > 0.05$). [1]Absolute growth rate. [2]Specific growth rate. P—partition.

DO, pH, and temperature of the water samples were also recorded when the sampling was performed. Measurements of water temperature, pH, and DO were performed *in situ* using the YSI multiprobe meter (model YSI 550A) and pH Cyber Scan waterproof, respectively. TAN and TN were analyzed using standard method adapted by Parsons et al. [20], whereas TSS and BOD_5 concentrations were determined in accordance with the standard methods [21]. The water samples that could not be analyzed immediately were frozen at −15˚C for a maximum of one week; this was within the recommended maximum storage time of two weeks by Parsons et al. [20].

2.3.6. Statistical analyses

Data analyses were performed using the SPSS ver. 13.0 statistical package (SPSS Inc. USA) assuming statistical significance if $p < 0.05$ (α set at 0.05). Data are presented as mean ± standard deviation (SD) and were subjected to two-way or multiple analysis of variance [22]. If significant statistical differences were indicated at the 0.05 levels, then Duncan's multiple range test was used to compare mean yields in order to identify significant differences [23].

3. Results and discussion

3.1. Fish growth and feed utilization

The growth response and feed utilization efficiency by the fish are presented in Tables 2 and 3. The results show that marble goby cultured in Big-P tubes and fed with tilapia produced the best growth and feed utilization. Among the diet treatment, the growth of fish fed with tilapia was significantly higher than those of fish fed with live carp and minced scads. With respect to tank design in each diet group, a significant higher growth and feed intake was observed for fish cultured in Big-P tubes and Big-P. In contrast, the fish cultured in Small-P showed the lowest weight gain and feed intake, recording an average daily feed intake ranging from 2.1 to 2.4% BW/d.

Among the diet treatment, FCE, PER, and PPV of fish compared with same tank design follow this sequence: Tilapia > Carp > Scads (Table 3). For tank design in each diet group, fish cultured in Big-P tubes and Big-P showed higher FCE, PER, and PPV. Fish cultured individually in partitions (Big-P tubes, Big-P, Small P) demonstrated a 100% survival, whereas a lower survival rate, ranging from 63 to 75%, was

Table 3
Feed intake (as fed) and protein utilization of marble goby in relation to different tank designs and diets

Diet: Tank design:	Total feed intake (g/fish)	Average feed intake (%BW/d)	FCE[1]	PER[2]	PPV[3] (%)
Tilapia					
Big-P tubes	468 ± 25^{a}	5.4 ± 0.3^{a}	0.46 ± 0.01^{a}	2.9 ± 0.1^{a}	55 ± 2^{a}
Big-P	424 ± 27^{b}	5.0 ± 0.4^{bc}	0.43 ± 0.02^{b}	2.8 ± 0.1^{b}	55 ± 3^{b}
Non-P tubes	378 ± 16^{d}	4.4 ± 0.2^{d}	0.40 ± 0.01^{c}	2.6 ± 0.1^{cd}	46 ± 1^{c}
Non-P	377 ± 18^{d}	4.4 ± 0.2^{d}	0.39 ± 0.01^{d}	2.5 ± 0.1^{de}	43 ± 1^{d}
Small-P	203 ± 17^{g}	2.4 ± 0.2^{g}	0.36 ± 0.01^{ef}	2.6 ± 0.2^{c}	45 ± 3^{c}
Carp					
Big-P tubes	415 ± 30^{bc}	4.9 ± 0.3^{bc}	0.39 ± 0.01^{d}	2.6 ± 0.1^{cd}	46 ± 2^{c}
Big-P	403 ± 19^{c}	4.8 ± 0.2^{c}	0.37 ± 0.02^{e}	2.4 ± 0.1^{e}	44 ± 1^{d}
Non-P tubes	377 ± 20^{d}	4.4 ± 0.3^{d}	0.35 ± 0.01^{gh}	2.3 ± 0.1^{f}	41 ± 1^{e}
Non-P	341 ± 12^{f}	4.0 ± 0.1^{f}	0.35 ± 0.01^{fg}	2.3 ± 0.0^{f}	41 ± 1^{e}
Small-P	183 ± 13^{h}	2.1 ± 0.2^{g}	0.34 ± 0.01^{h}	2.3 ± 0.0^{f}	39 ± 1^{f}
Scads					
Big-P tubes	433 ± 21^{b}	5.1 ± 0.3^{b}	0.31 ± 0.01^{i}	2.1 ± 0.0^{g}	38 ± 1^{f}
Big-P	413 ± 10^{bc}	4.9 ± 0.1^{bc}	0.31 ± 0.01^{i}	2.1 ± 0.0^{g}	36 ± 1^{g}
Non-P tubes	363 ± 13^{de}	4.3 ± 0.2^{de}	0.30 ± 0.01^{j}	2.0 ± 0.0^{h}	34 ± 1^{h}
Non-P	350 ± 12^{ef}	4.1 ± 0.1^{ef}	0.29 ± 0.01^{j}	2.0 ± 0.0^{h}	34 ± 1^{h}
Small-P	193 ± 13^{gh}	2.3 ± 0.2^{g}	0.28 ± 0.005^{k}	1.9 ± 0.0^{i}	32 ± 1^{i}

Values are mean ± SD ($N = 3$) and means with the same superscript in the same column are not statistical different ($p > 0.05$). [1]FCE = Weight gain (g)/Feed intake (g). [2]PER = Weight gain (g)/Protein intake (g). [3]PPV = (Protein gain (g)/Protein intake (g)) × 100. P—partition.

observed in fish cultured in Non-P tubes and Non-P in all diet treatments.

Fish fed with live food (tilapia, carp) showed good growth, feed consumption, FCE, PER, and PPV comparable to that of fish fed with dead diet (scads). A more pronounced effect on growth and feed utilization was observed for fish fed with active live tilapia, which is commonly known as a high nutritional diet. This could be attributed to the higher ingested protein quality of this diet for marble goby nutrition, supplying the fish's proper EAAs for metabolism and muscle growth [24].

The use of minced scads slices as a feed resulted in a significant decrease in final weight, SGR, and PPV compared to those of fish fed with live tilapia and carp. The very low-growth performance and nutrient utilization of fish fed with this diet were most likely due to the low feed intake and the poor amino acid balance of minced scads. These results are in agreement with the findings of other workers on carnivorous species fish such as Atlantic salmon, red drum, and Asian seabass [25–27].

For tank design, SGR and FCE for the fish cultured in Big-P tubes and Big-P were much higher than those of fish cultured in other tank designs. This could be due to the fact that the stress imposed on the fish was kept to a minimum in these tank designs as the marble goby, being a cannibalistic and territorial fish, was kept apart from each other in each partition. This tank design was designed to prevent overcrowding and cannibalism, which have protected the fish from fighting, biting, and eating each other. As a result, the fish had less chances of getting wound and disease while being supplied with sufficient high protein diet. All these were likely to have contributed to the growth and feed utilization of the fish.

A more superior effect on the growth and feed utilization was observed for fish cultured in big space plastic partitions with PVC tubes (Big-P tubes). Marble goby is a demersal fish normally found on the bottom of quiet streams, canals, and reservoirs [28]. The fish is a nocturnal hunter which is benthic carnivorous and active during night time. This indicates their natural preference of hunting food in a dusky or

Table 4
Waste production rates by marble goby

Diet: Tank design:	TAN mg TAN/kg d	TN mg N/kg d	BOD_5 mg DO/kg d	TSS g TSS/kg d
Tilapia				
Big-P tubes	140 ± 22^{a}	197 ± 28^{ab}	232 ± 36^{a}	1.8 ± 0.1^{bc}
Big-P	151 ± 28^{ab}	211 ± 38^{ab}	250 ± 46^{ab}	1.7 ± 0.1^{b}
Non-P tubes	170 ± 19^{abc}	238 ± 25^{abc}	282 ± 31^{abc}	1.8 ± 0.2^{bc}
Non-P	187 ± 19^{c}	258 ± 24^{c}	310 ± 32^{bc}	1.8 ± 0.2^{bc}
Small-P	149 ± 25^{ab}	242 ± 30^{ab}	247 ± 42^{ab}	1.4 ± 0.2^{a}
Carp				
Big-P tubes	182 ± 24^{bc}	242 ± 30^{bc}	302 ± 39^{bc}	1.8 ± 0.1^{bcd}
Big-P	197 ± 17^{c}	260 ± 21^{c}	326 ± 28^{c}	1.9 ± 0.1^{bcde}
Non-P tubes	208 ± 14^{c}	276 ± 17^{c}	344 ± 24^{c}	1.9 ± 0.1^{bcde}
Non-P	198 ± 15^{c}	260 ± 17^{c}	315 ± 48^{c}	1.8 ± 0.1^{bc}
Small-P	149 ± 19^{ab}	194 ± 23^{a}	247 ± 31^{ab}	1.3 ± 0.1^{a}
Scads				
Big-P tubes	257 ± 22^{d}	320 ± 24^{d}	426 ± 35^{d}	2.1 ± 0.1^{e}
Big-P	261 ± 14^{d}	323 ± 15^{d}	433 ± 24^{d}	2.0 ± 0.1^{de}
Non-P tubes	259 ± 14^{d}	321 ± 16^{d}	429 ± 23^{d}	2.0 ± 0.1^{cde}
Non-P	262 ± 18^{d}	319 ± 20^{d}	434 ± 30^{d}	1.9 ± 0.1^{bcde}
Small-P	198 ± 23^{c}	240 ± 25^{bc}	328 ± 38^{c}	1.4 ± 0.2^{a}

Values are mean ± SD ($N = 3$) and means with the same superscript in the same column are not statistical different ($p > 0.05$).

darker condition (especially at night). The results of providing PVC tubes to the fishes as a shade shelter in this study had significantly improved their growth and feed conversion. These have reflected the role of PVC tubes in providing the simulative dark night condition as their natural habitat condition, which thus enhances the feeding frequency and the growth of the fishes. Similar findings were reported by Baras et al. [29] on juveniles vundu catfish. The authors reported that feeding the fish under the conditions of darkness produced higher growth rates and feed conversion, lower mortality, and fewer losses due to cannibalism.

Lower growth rate, feed intake, and survival were observed for fish cultured in Non-P tubes and Non-P. In this study, the fish cultured in these tank designs were observed to either gather together at the corner of the tank, or stayed together inside the PVC tubes provided. This had created an overcrowding effect and the fish (with a cannibalistic and territorial nature) began to fight, nip, and bite on each other. This resulted in serious open wounds followed by infections of fungus on several body parts including fins, gill side, and tail of the fish. In addition, some fishes were infected with eye diseases and this resulted in less feed intake and starvation. These results suggest that the fish were likely to become more cannibalistic as a result of being less tolerant to the stress of increased overcrowding. Furthermore, the overcrowding may lead to a deviation in the fish sizes in the enclosure, mainly due to the inability of smaller fish to get access to the food when the feeding is conducted. Thus, this situation was likely to account for the poor feed conversion rates and size variation because some of the fish population could become poorly conditioned through starvation and bullying. This in turn promoted cannibalism and affected the growth performance, feed intake, and survival of the fish.

For fish cultured in narrow space net partitions (Small-P), the fish was highly stressed because there was virtually no space for them to move or swim around. When they moved, their body was often scratched as a result of being forced to rub on the sides or bottom of the enclosure (net partition). This led to lesions or wounds that became easy entry sites for pathogens. In addition to being stressed, the fish also faced difficulty in catching their feed, especially when they are fed with live tilapia and carp, as these small live feeds were observed to always swim around in order to escape from being eaten. As a result, these marble goby had to use up a lot of strength in catching those live feeds. This was likely to lead to the decrease in feed intake and growth as more energy from the diet was used for catabolism rather than for growth. As a consequence of these unfavorable factors, the fish cultured in Small-P showed the lowest growth and feed utilization.

3.2. Waste production

The mean daily rates of waste production by marble goby are presented in Table 4. Among the diet treatment, it was revealed that marble goby fed with minced scads slices showed the highest TAN production compared to those of fish fed with live food (Tilapia and Carp). The ammonia produced by fish cultured in Big-P tubes and Big-P compared with same tank design follows this sequence: Scads > Carp > Tilapia. With respect to tank design, TAN production by fish cultured in Small-P (which was fed with Carp and Scads) was significantly lower than that those of fish cultured in other tank design due to lower feed intake, yet no significance difference of TAN production was observed between the fish cultured in different tank design in the Tilapia - fed group.

Analyses of BOD_5 showed that the fish fed with minced scads exerted the highest oxygen demand. The higher metabolism of fish in this diet group is likely to have an increasing effect on the oxygen demand. There were no observable trends in the overall BOD_5 results among the fish cultured in different tank design. The daily BOD_5 exerted by marble goby in this study ranged from 232 to 434 mg DO/kg/d. The results of the analyses of TSS are also presented in Table 4. Among the diet treatment, a significant higher TSS concentration was observed for fish fed with minced scads compared with other diets. With respect to tank design, the lowest TSS concentration was shown by fish cultured in narrow space net partitions (Small-P). In this study, the daily TSS concentration ranged from 1.3 to 2.1 g TSS/kg/d.

The results on waste production correlated well with the results of growth and dietary utilization. Dosdat et al. [30] concluded that ammonia production was linked to ingested protein. In the present study, the fish fed with the tilapia diet and cultured in the Big-P showed the best growth and nutrient utilization and exhibited the lowest amount of ammonia production. The lower production levels shown by the Tilapia-fed group could be attributed with the protein quality of Tilapia, which may be of higher quality compared to the protein quality of the carp and scads. These results are in agreement with the findings by Murat et al. [31] on turbot nutrition.

For the fish fed with minced scads, which exhibited the highest waste production, this correlates well with other nutritional parameters, and it is thought to be due to the deterioration of scads diet during storage. It has been reported that fish would not fully utilize the feed if the feed was deficient in nutrients due to break down over time, in addition, the feed would increase the amount of waste produced by the fish [24]. Furthermore, amino acid imbalance and digestibility could have influence on the low utilization of diets and nutrients in the groups of fish fed with minced scads, resulting in high waste production by the fish. Scads is likely to be a low-quality feed that contains considerable amounts of poorly balanced protein sources, which could not only fail to meet the fish's proper EAA requirements, but it could also result in the absorption of some amino acids in amounts beyond the fish's ability to utilize them for muscle growth. When more amino acids are absorbed beyond the amounts that can be utilized by the fish, this leads to waste being excreted via the gills as dissolved unionized ammonia (NH_3) [24]. Furthermore, the fish were fed to satiation in this study. This could cause the fish to consume more feed than that is required for optimal growth rate and nutrient utilization, thus resulting in higher amounts of waste production.

The water used for the culture of marble goby in the study had an undetectable initial concentration of total suspended solids (TSS). The TSS materials determined in this study were likely to be comprised of a small fraction of uneaten feed and the excreted fecal material produced by the fish. The TSS measured for the fish fed with minced scads were significantly higher than those of fish fed with live diet (tilapia and carp). It was visually observed that higher feces were excreted by the fish and higher amounts of uneaten feed were spitted out from the mouth of marble goby fed with the scads diet. These are likely to account for the higher TSS values. With respect to tank design, the fish cultured in narrow space net partitions (Small-P) showed the lowest TSS values. This is likely due to the low feed intake by the fish in this tank design.

4. Conclusions

Tank design and feed type were found to have effects on the growth and the waste production of marble goby. Live food, particularly tilapia, was found to be the preferential diet for marble goby by showing the best growth and feed utilization, and also the lowest waste production compared to that of fish fed with trash fish or artificial feed. The use of big space plastic partitions and PVC tubes associated with

RAS showed advantages in improving both the growth and survival of the fish, in addition to reducing the waste production by the fish. Our results indicate that the use of culture tank with big partitions and PVC tubes coupled with a RAS, which also combined with the use of live tilapia as a feed, show exceptional promise as a means for the culture of cannibalistic aquaculture species such as marble goby. This approach and its unique combination of properties ensures that minimum stress is imposed on the fish as a result of the good water quality condition provided by the RAS and also the spacious partition that prevents overcrowding and cannibalism of fish.

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