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Optimizing Red Tilapia Juvenile (*Oreochromis niloticus*) Nursery in Recirculating Aquaculture with Ultrafine Bubbles System at Variable Stocking Densities

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ABSTRACT The increased demand for red tilapia (*Oreochromis niloticus*) production requires a sufficient supply of high-quality juveniles. Technological innovation is crucial for developing quantifiable, highly productive, efficient, environmentally sustainable, and ecologically sound juvenile production systems. This study aimed to analyse the effect of high stocking density on the growth performance of red tilapia juveniles cultured using ultrafine bubble technology in a recirculating aquaculture system (UFBs-RAS). A completely randomised experimental design was used with four stocking density treatments: one control treatment (4 fish/L with aeration) and three treatments under the UFBs-RAS system at 4, 6, and 8 fish/L densities. Each treatment was replicated four times. The juvenile red tilapia used in this study had an average initial total length of 4.34 ± 0.23 cm and a weight of 1.47 ± 0.31 g. They were obtained from fishpond research at the FINDER UCoE Experimental Station, Universitas Padjadjaran. The findings indicated that UFBs-RAS facilitated optimal production performance, even at the maximum stocking density of 8 fish per liter. The performance metrics comprised a survival rate of 98.75%, a specific growth rate in weight of 4.93 ± 0.062%/d, a specific growth rate in length of 3.88 ± 0.05%/d, a protein efficiency ratio of 2.48 ± 0.02, a feed conversion efficiency of 96.5 ± 0.58%, and a coefficient of variation of 33.7 ± 1.2%. These data validate that incorporating UFBs-RAS is a viable and efficient method to improve the quality and productivity of red tilapia juveniles.

Keywords: High density; production; red tilapia; ultrafine bubbles

INTRODUCTION

Red tilapia (*Oreochromis niloticus*) is an aquaculture commodity with high economic value in domestic and export markets. This has increased tilapia production in 2021 by 9.63%, with a production of 1.35 million tonnes valued at Rp33.62 trillion (KKP, 2021). The substantial expansion of tilapia aquaculture demands a reliable and adequate supply of high-quality juvenile fish. Therefore, there is a need for a technological breakthrough that can produce tilapia juveniles that are measurable, highly productive and efficient, as well as environmentally friendly and sustainable (Hernández *et al.*, 2021).

One strategic and potential fish farming system to be developed is the Recirculating Aquaculture System (RAS) (Ahmed & Turchini, 2021). RAS allows fish farming in a controlled environment, thereby minimizing direct interaction with the external environment. Rearing fish in a RAS offers relatively high productivity, as this system can maintain optimal water quality even at high stocking densities (Timmons *et al.*, 2002) and uses water very efficiently (Murray *et al.*, 2014).

The success of fish farming in the RAS must consider biofiltration, circulation, aeration, and degassing (Malone, 2013). Ultrafine bubbles become very important to be integrated into the system to improve the performance of the RAS system. Ultrafine bubbles (UFBs) are air bubbles with very small sizes (≤500 nm) (Subhan *et al.*, 2022) that function to increase dissolved oxygen, reduce ammonia nitrogen (NH3-N), and control parasites (Subhan *et al.*, 2021). The device also functions to float suspended particles and has antibacterial capabilities (Wang & Zhang, 2017; Temesgen *et al.*, 2017) as well as being able to influence physiological effects, increasing blood flow (Tsuge, 2015) and fish growth (Murray *et al.*, 2014).

Research on integrating UFBs generators in RAS can improve the survival rate and specific growth rate of catfish larvae (Subhan *et al.*, 2022). Furthermore, Hanif (2021) reported that the use of nano bubbles in RAS can enhance the growth performance of *Epinephelus* sp., yielding an SGR value of 4.25 ± 0.07%/d, FCR of 1.11, SR of 100%, and productivity of 2.78 kg/m². Furthermore, using a nanobubble generator in *Litopenaeus vannamei* culture has proven effective in increasing productivity to 8.7 kg/m³ (Rahmawati *et al.*, 2021). This research aims to evaluate the effectiveness of integrating the UFBs-RAS system in enhancing the production performance of red tilapia juveniles at varying stocking densities. The expected outcomes include improved growth rates, survival, and system efficiency. The findings of this study are anticipated to provide practical insights for optimising intensive aquaculture practices, thereby contributing to increased productivity and reduced operational costs for fish farmers.

MATERIALS AND METHODS

Installation of equipment

The UFBs-RAS system setup used for red tilapia juveniles in this study (Figure 1) comprised three primary media: two ultrafine-bubble tanks (20 L capacity), 16 cylindrical rearing containers (15 L capacity), and a single water-holding container (80 L capacity). These components were integrated into a single RAS designed for juvenile rearing and water treatment. Aeration was provided by an ultrafine-bubble generator (125-Watt cap), which was supplied with pure oxygen at a 0.1 L min¹ (Subhan *et al.*, 2022). Water was delivered to each rearing container at 0.5 L min¹, maintaining a constant volume of 15 L. Effluent from each aquaculture rearing unit was collected through PVC piping and directed into a filtration chamber containing Japanese mat, filter cotton, bioballs, and zeolite. To stabilize the water temperature for tilapia culture (25 °C), four thermostats equipped with a 100-watt capacity were used.

Juvenile tilapia preparation

The red tilapia juveniles used in this study were relatively uniform in size, measuring 3–5 ± 0.23 cm in total length

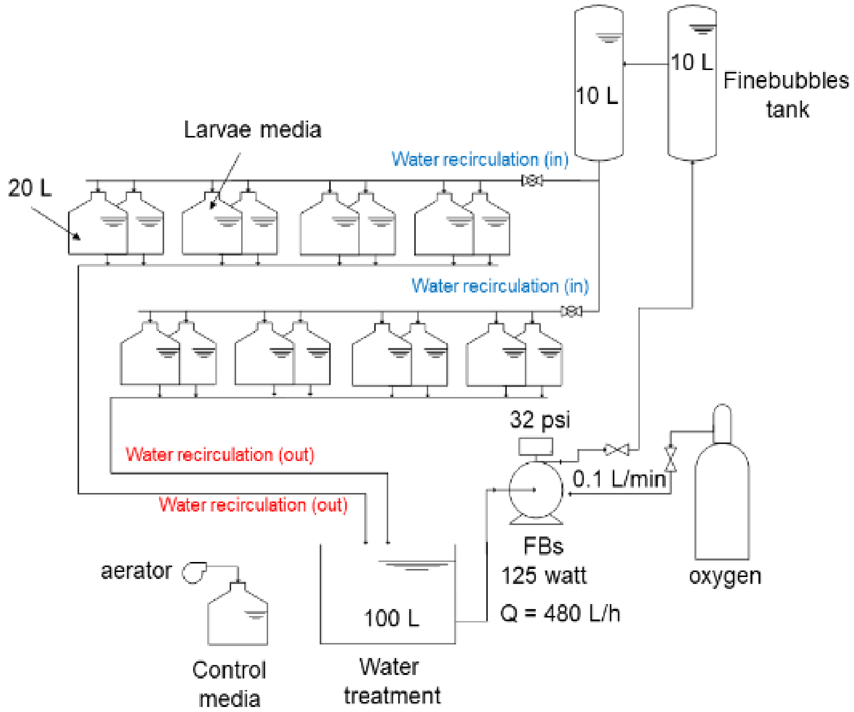

Figure 1. Instalasi UFBs-RAS (Subhan *et al.*, 2021).

and 0.7-1.2 ± 0.31 g in body weight. The seed was obtained from fishpond research conducted at the Centre of Excellence for Functional Nano Powder, Universitas Padjadjaran. The red tilapia was acclimatized in a fibre tank measuring 100 × 50 × 30 cm with aeration for 2 hours. Thereafter, coarse salt and Redbluedox were added to the tank at concentrations of 0.5 g/L and 0.1 mL/L, respectively, to maintain the fish's osmotic balance and prevent parasitic growth.

Feeding management

Two types of artificial feed were used in this study. During the acclimation period (7 days), the red tilapia juvenile was fed a commercial feed of PF 500, with a pellet size of 0.5-0.7 mm. This feed contained a minimum of 39% protein, 5% fat, a maximum of 4% crude fibre, 11% ash, and 10% moisture. For the main feeding period, which lasted 28 days from the beginning to the end of the experiment, the fish were fed on PF 1000 with a pellet size of 1.3-1.7 mm. This feed had a protein content of 39-41%, a minimum of 5% fat, 6% crude fibre, 12% ash, and 10% moisture. Feed was administered to apparent satiation, three times daily.

Water quality measurement

Water quality parameters were measured using several instruments: dissolved oxygen (DO) and temperature were assessed with a Milwaukee M1605 portable DO meter; pH was measured using a Milwaukee MW 101 pH meter; total dissolved solids (TDS) were determined using the Milwaukee EC59/EC60 device; and nitrogenous compounds-including total ammonia nitrogen (TAN), nitrite, and nitrate-were analyzed using the Sera Aqua Test Box water testing kit.

Methods

The method employed in this study was an experimental approach using a Completely Randomised Design (CRD), consisting of four stocking density treatments with four replications. The stocking density treatments tested were as follows: A (Stagnant Aeration Water/SAW, 4 fish/L), B (UFBs, 4 fish/L), C (UFBs, 6 fish/L), and D (UFBs, 8 fish/L). The stocking densities for treatments A and B were referred to by Dawood *et al*. (2023), who reported that a density of 4 fish/L in a RAS system provided optimal growth rates for red tilapia juveniles ranging from 2.72 ± 0.03 to 2.90 ± 0.02% per day.

Survival rate

The survival rate of red tilapia juvenile was determined by counting the number of fish at the beginning and at the end of the experiment. According to Goddard (1996), survival rate can be calculated using the following formula:

$$SR(\%) = \frac{Nt - n}{Nt - o} x\ 100$$

SR, Survival Rate (%); Nt-n, Total number of live fish at the end of the experiment; Nt-0, Total number of juveniles at the beginning of stocking.

Specific growth rate

The production performance of red tilapia juvenile was determined based on specific growth rate (SGR). The measured growth parameters included individual average weight and daily biomass gain. The calculation of growth rate followed the formula proposed by Bidlack (2000).

Specific Growth Rate (SGR) for weight is calculated using the formula:

$$SGR(\%g/day) = \left(\frac{lnWt - lnW0}{t}\right) x\ 100$$

Wt, Final average individual weight (g); W0, Initial average individual weight (g); t, Duration of rearing period (days)

The specific growth rate for length is calculated using the formula:

$$SGR(\%mm/day) = \left(\frac{lnLt - lnL0}{t}\right) x\ 100$$

Lt, Final average individual length; L0, Initial average individual length; t, Duration of the rearing period.

Protein efficiency ratio
This parameter represents the ratio of fish biomass to the amount of protein consumed. The Protein Efficiency Ratio (PER) is calculated using the formula according to Slembrouck *et al*. (2009):

$$PER = \left(\frac{Wt - Wo}{Pi}\right)$$

Wt, Final biomass weight (g); Wo, Initial biomass weight (g); Pi, Weight of protein consumed (g).

Feed conversion efficiency
Feed conversion efficiency (FCE) is calculated using a formula based on the increase in the ratio of the seed red tilapia biomass to the total biomass of feed used (Kim & Lee, 2016):

$$FCE = \left(\frac{Wt - Wo}{Fi}\right) x\ 100\%$$

Wt, Final biomass weight (g); W0, Initial biomass weight (g); Fi, Biomass weight of feed given (g).

Coefficient of variation
Coefficient of variation is the ratio of the standard deviation to the mean size, expressed as a percentage. The coefficient of variation (CV) for the test fish is calculated using the formula by Warwick *et al*. (1995) as follows:

$$CV(\%) = \left(\frac{SD}{\bar{x}}\right) x\ 100\%$$

CV, Coefficient of Variation (%); SD, Standard Deviation; $\bar{x}$, Average Size.

Statistical analysis
Survival rate, specific growth rate, protein efficiency ratio, feed conversion efficiency, and coefficient of variation of seed red tilapia were analyzed using ANOVA at a 95% confidence level. If the calculated F value > the table F value, the Tukey test is followed. Meanwhile, the observation of water quality is conducted through descriptive analysis.

RESULTS AND DISCUSSION

Water quality
Table 1 presents the results of this study's water quality observation. The parameters of water quality showed a difference in the aeration system culture between SAW and UFBs-RAS.

Dissolved oxygen saturation (DOsat) levels in the UFBs-RAS system were higher than the SAW (Figure 2) due to the UFBs generator, which can enrich dissolved oxygen in media culture according to Subhan *et al*. (2021). The DOsat levels decreased during the observation period, likely due to the increased biomass of fish, which raises the oxygen demand for metabolic processes (Tanjung *et al*., 2019). High dissolved oxygen levels can stimulate fish growth because increased oxygen availability enhances metabolic rates. According to Thorarensen *et al*. (2017), oxygen saturation is very important in affecting the specific growth rates of fish.

Table 1. Water quality performance during the experiment.

Parameter	Aeration system culture	
	SAW	UFBs-RAS
DOsat (%)	55.76-61.67	70.51-74.34
Temperature (°C)	26	26
pH	6.58-6.70	7.0-7.4
TDS (mg/L)	147-182	219-413
TAN (mg/L)	4-8	0.5-8
NH_3 N (mg/L)	0.01-0.012	0-0.002
NO_2-N (mg/L)	1-2	0.5-2.00
NO_3-N (mg/L)	5-10	0-10

The temperature during the study remained within the optimal range for the growth of red tilapia juveniles in both the SAW and UFBs-RAS systems, consistently at 26 °C. A thermostat was installed to stabilize the temperature. According to SNI 6141-2009, the recommended temperature range for tilapia juveniles is between 25 °C and 30 °C. The maintained temperature during the experiment supports fish health and feeding behaviors. Water temperature affects all aspects of fish physiology, such as respiration, reproduction, and growth. It also influences appetite, digestion, and metabolic rate, ultimately affecting growth (Burggren *et al*., 2019).

Measuring pH in the SAW and UFBs did not show significant fluctuations and remained within optimal levels (Fig-

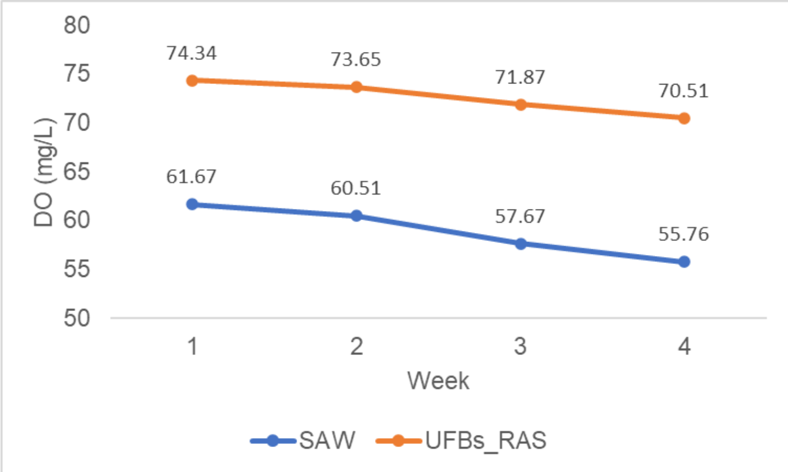

Figure 2. Comparison of dissolved oxygen (DO) levels between SAW and UFBs-RAS.

ure 3). According to SNI 6141-2009, the optimal pH for tilapia juveniles is 6.5 to 8.5. Maintaining this pH value can support healthy fish; however, the suboptimal pH value affects stress, disease, reduced productivity, and poor growth (Danaher *et al.,* 2013). In addition, the pH value greatly affects the concentration of ammonia (NH_3N), which is very dangerous for aquaculture conditions (Timmons & Ebeling, 2010).

The UFBs-RAS system exhibited relatively higher TDS concentrations, although a declining trend was observed over the final research (Figure 4). This trend aligns with findings reported by Pratama *et al*. (2021), who noted a gradual reduction in TDS levels during tilapia rearing in RAS. The TDS levels observed are likely influenced by the RAS's efficiency and the filtration media's effectiveness in removing dissolved solids (Sulastri & Nurhayati, 2014). Elevated TDS levels initially may be attributed to heightened fish activity, residual feed, and metabolic waste. Nevertheless, TDS values across all treatments remained below 1000 ppm, which falls within the acceptable range for aquaculture operations. Under Government Regulation 82 of 2001, the threshold for TDS in Class III water bodies designated for aquaculture is set at less than 1000 ppm (Effendi *et al.*, 2015).

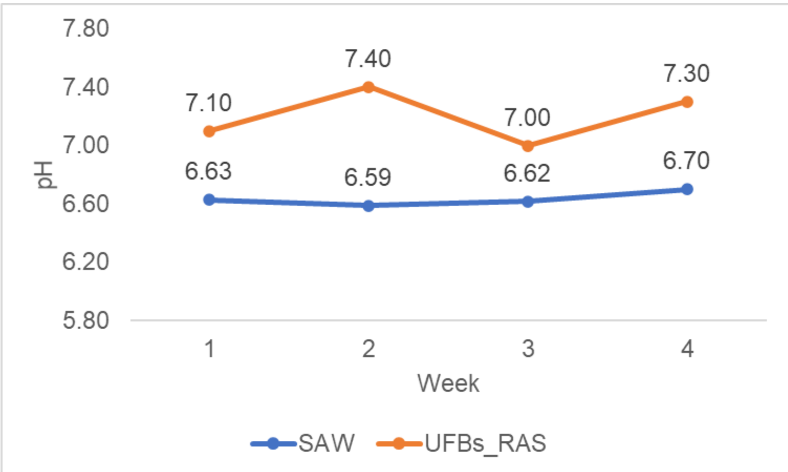

Figure 3. Comparison of pH levels between the SAW and UFBs-RAS.

Observations of TAN and ammonia over 30 days showed differences between SAW as the control and the UFBs system treatments (Figure 5). The SAW system without filtration media exhibited higher concentrations of TAN (4 to 8 mg/L) and ammonia (0.01 to 0.012 mg/L), which decreased in subsequent weeks. However, UFBs-RAS had lower levels of TAN and ammonia with values ranging from 0.5 to 8 ppm and 0 to 0.0002 mg/L, respectively. This is due to the role of the UFBS generator, which can reduce ammonia from aquaculture effluent by 40% (Subhan *et al.,* 2021). Additionally, it is supported by a filtration medium that encourages the growth of nitrifying bacteria, which break down ammonia. It is the most toxic and poses a greater danger to fish because it diffuses easily through the gills into the blood (Randall & Tsui, 2002). The excessive ammonia levels cause fish mortality, as excessive ammonia interferes with oxygen transport in the blood, potentially leading to death (Monalisa & Min-

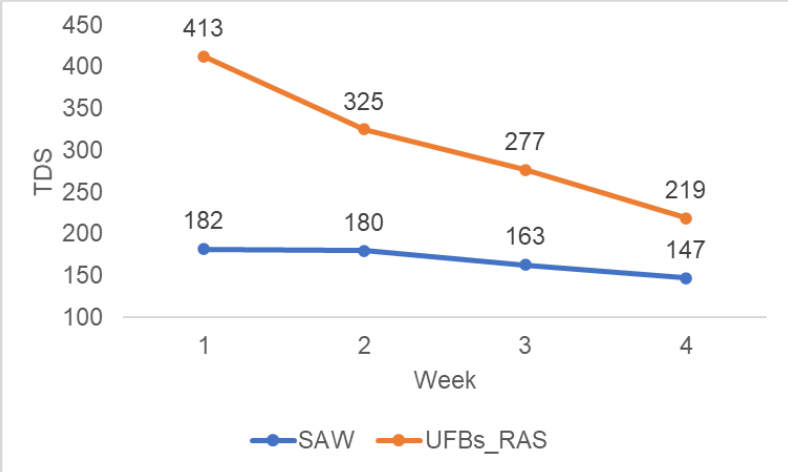

Figure 4. Comparison of TDS between aeration and UFBs-RAS systems.

ggawati, 2010). Ammonia levels in UFBs-RAS were below 0.02 mg/L, which is acceptable for tilapia culture based on SNI 6139-2009.

Based on Figure 5, the nitrite and nitrate content in the UFBs-RAS system is lower compared to the SAW system. Nitrite and nitrate levels in the UFBs-RAS treatment were initially high but declined in later observations, which may be linked to ammonia reduction facilitated by sufficient oxygen for nitrification. This aligns with Danaher *et al*. (2013) that nitrification is ineffective without adequate DO. High nitrite levels in the SAW system (1 to 2 mg/L) negatively affect fish appetite due to reduced oxygen-carrying capacity of the blood. This occurs because nitrite oxidizes hemoglobin into methemoglobin, which cannot transport oxygen (Dawood, 2021) and causes brown blood disease, leading to fish suffocation (Chappell, 2008).

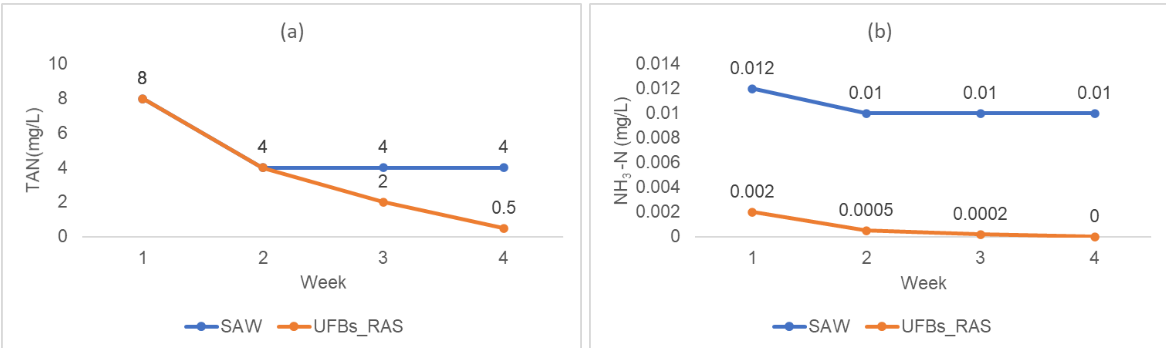

Figure 5. (a) Comparison of total ammonia nitrogen (TAN) levels between SAW and UFBs-RAS systems (b) comparison of unionized ammonia (NH_3-N) between SAW and UFBs-RAS systems.

Growth performance

The growth performance results are presented in Table 2. There were significant differences (p<0.05) in survival rate (SR), specific growth weight (SGR weight), specific growth length (SGR length), protein efficiency ratio (PER), and feed conversion efficiency (FCE) between the SAW system (treatment A) and the UFBs-RAS systems (treatments B, C, and D). In contrast, the coefficient of variation was significantly lower (p<0.05) in treatment A compared to the UFBs-RAS treatments.

Survival rate

Based on the study's results (Figure 7), the survival rate of red tilapia juveniles ranged from 65.83 ± 10.63% to 98.75 ± 1.97%. Analysis of variance (ANOVA) showed a statistically significant difference among treatments (P < 0.05). Further analysis using Tukey's post-hoc test revealed a significant difference (P < 0.05) between treatment A with SAW and the UFBs-RAS treatments: B, C, and D. However, no significant differences (P > 0.05) were observed among the UFBs-RAS treatments themselves.

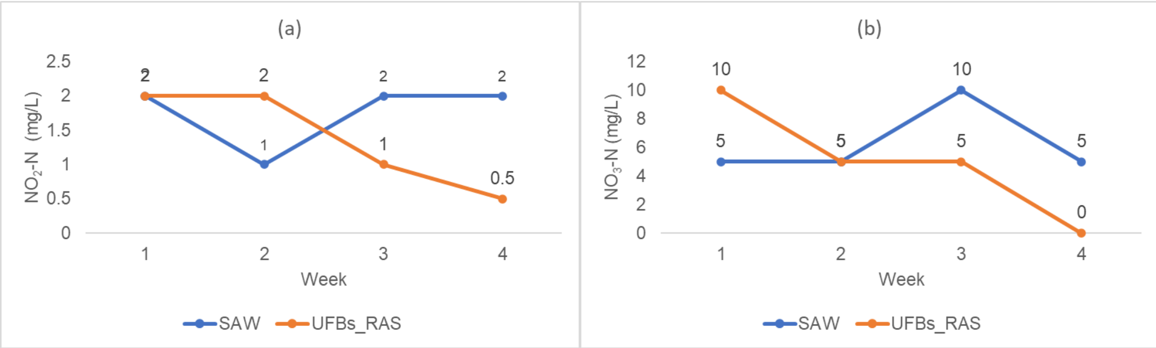

Figure 6. (a) Comparison of NO_2-N levels between SAW and UFBs-RAS systems (b) comparison of levels NO_3-N between SAW and UFBs-RAS systems.

The highest survival rate was shown in the treatment of stocking density in UFBs-RAS, reaching 94.45% to 98.75%. This outcome is attributed to the high availability of dissolved oxygen (>70%) and low ammonia concentration (≤0.002 mg/L). Similarly, Dawood *et al*. (2023) reported findings where we observed a 97.9% survival rate at a stocking density of 3 fish/L for seed tilapia reared in a conventional RAS. Enhancing oxygen levels can reduce glucose and lactate concentrations in the liver, indicating that tilapia reared under these conditions are healthy and possess a high well-being index (Li *et al.*, 2023). In contrast, low survival was observed at treatment A (65.83%), which was caused by insufficient dissolved oxygen, due to a failure to support the hematological performance. This is supported by Li *et al*. (2020), who reported that low dissolved oxygen levels can elevate stress in fish, as indicated by increased glucose, lactic acid concentrations, and red blood cell counts. In addition, the primary factor contributing to the reduced survival rate was the accumulation of ammonia (0.012 mg/L) derived from

Table 2. Growth performance parameters of red tilapia juvenile.

Parameter	Treatment			
	A (SAW, 4 fish/L)	B (UFBs, 4 fish/L)	C (UFBs, 6 fish/L)	D (UFBs, 8 fish/L)
SR (%)	65.83 ± 10.2^{a}	95.42 ± 2.84^{b}	94.44 ± 3.14^{b}	98.75. ± 1.98^{b}
SGR in body weight (% per day)	2.62 ± 0.09^{a}	4.84 ± 0.12^{bc}	4.72 ± 0.1^{b}	4.93 ± 0.062^{b}
SGR in total length (% per day)	1.08 ± 0.29^{a}	3.74 ± 0.071^{b}	3.57 ± 0.035^{b}	3.88 ± 0.05^{b}
PER	1.84 ± 0.09^{a}	2.38 ± 0.009^{b}	2.33 ± 0.036^{c}	2.48 ± 0.02^{d}
FCE (%)	72 ± 3.7^{a}	92.75 ± 0.5^{bc}	90.5 ± 1.3^{b}	96.5 ± 0.58^{c}
CV weight (%)	28.3 ± 0.01^{a}	31,9± 0.02^{ab}	32.6 ± 0,02^{b}	33.70 ± 1.55^{b}

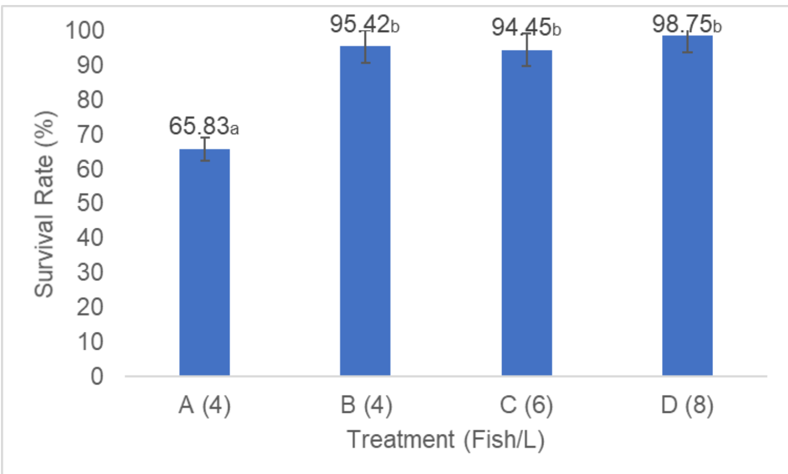

Figure 7. Survival rate of juvenile red tilapia at different stocking densities in SAW and UFBs-RAS systems.

metabolic waste. This is due to the absence of a filtration system that supports bacteria in reducing ammonia. Ammonia accumulation due to gill epithelial damage makes them more susceptible to disease and high mortality (Bernardi *et al*., 2018). Excess ammonia is primarily problematic because it alters the cell pH, depletes vital components required for energy production, and disrupts nerve signaling (Bombardelli *et al*., 2004).

Specific growth rate

The growth performance of red tilapia juveniles (Figure 8) showed SGR weight ranging from 2.62 ± 0.09% to 4.93 ± 0.062%/d/d and SGR length of 1.08 ± 0.29% to 3.88 ± 0.05%/d/d. ANOVA analysis indicated significant differences among treatments for weight and length growth rates ($p < 0.05$). Tukey's post hoc test revealed that the control treatment (SAW at 4 fish/L) had significantly lower SGR (weight and length) compared to the stocking density at UFBs-RAS system (A, B and D $p < 0.05$) and there was no significant difference between treatments at UFBs-RAS system ($p > 0.05$). These results suggest that the UFBs-RAS system supports better growth performance in red tilapia juveniles compared to SAW as conventional aeration systems, even under higher stocking densities.

Juvenile red tilapia raised in the UFBs-RAS system showed much better growth in both length and weight compared to those in the control group (SAW), especially in treatment D. In this treatment, the fish had a weight growth rate of 4.93%/d and a length growth rate of 3.88%/d. This is much higher than the control group, which only reached 2.62% per day in weight and 1.08% per day in length. These results were also better than those reported by Dawood *et al.* (2023) and Dahlan et al. (2022). The growth rate in the UFBs-RAS system is better because the oxygen levels were well-saturated (above 70%), which helps fish breathe more easily and use their energy for growth. According to Howerton (2001), when oxygen levels are high, fish do not need much energy to breathe, so more energy can go toward growing. Also, the ammonia levels in this system were very low (≤0.002 mg/L), which is important because even small amounts of ammonia can affect fish growth (Ijaz *et al*., 2010).

On the other hand, fish in the SAW system (control) grew more slowly because the oxygen levels were low (only 50-60%), which is not enough to support healthy metabolism. Thorarensen *et al.* (2017) stated that oxygen levels below 65% (hypoxia) can harm fish growth. In such conditions, fish struggle to get enough oxygen, which makes them breathe harder and use more energy, leaving less for growth (Chatvijitkul *et al*., 2017; Buentello *et al*., 2000; Lakani *et al*., 2013). Another reason for the poor growth is the SAW treatment's high ammonia levels (about 0.012 mg/L). Elevated ammonia can reduce appetite and slow growth by lowering the blood's oxygen capacity (Ijaz *et al*., 2010). It can also damage tissues, reduce the immune system, and increase the risk of death (Lemarie *et al*., 2004; Kim & Kang, 2015). The significant difference in ammonia levels between the two systems clearly impacted fish growth, highlighting the importance of maintaining low ammonia concentrations for healthy and efficient aquaculture.

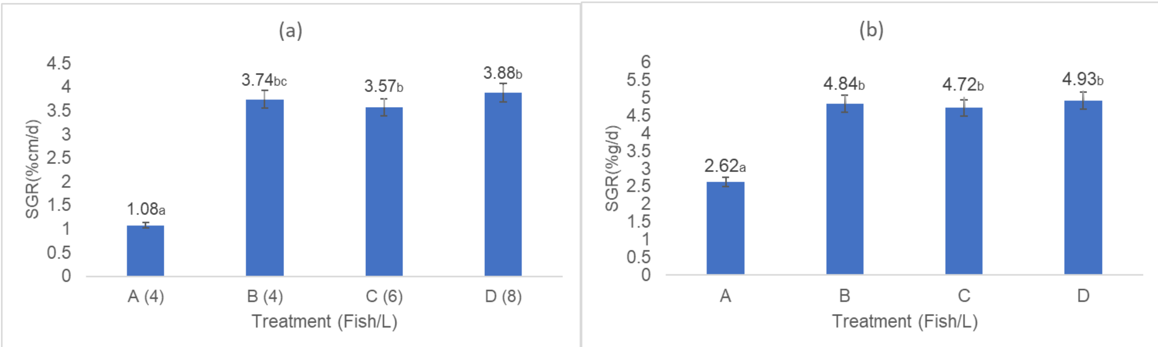

Figure 8. (a) Specific length growth rate of red tilapia juveniles at different stocking densities in SAW and UFBs-RAS systems. (b) Specific weight growth rate of red tilapia juveniles at different stocking densities in SAW and UFBs-RAS systems.

Protein efficiency ratio

Protein efficiency ratio (PER) is a parameter used to determine the utilization of protein in feed for fish growth and is closely related to the nutritional content of the feed. This study's protein source came from commercial feed containing 39% - 41% protein. Based on the calculations, the PER values in this study ranged from 1.84 ± 0.09 to 2.48 ± 0.02. Statistically, all treatments showed significant differences ($p<0.05$). The highest PER value was observed in treatment D, followed by treatment B, C, and A, as the control treatment with SAW.

The PER values of red tilapia juveniles reared in the UFBs-RAS system under normoxic conditions showed high results, ranging from 2.33 ± 0.04 to 2.48 ± 0.02, compared to the SAW system (control), which was 1.82 ± 0.09. The treatment with the highest stocking density (D) yielded the highest PER value. Based on these findings, it can be concluded that a stocking density of 8 fish/L represents the optimal density for rearing juvenile red tilapia in the UFBs-RAS system to achieve high productivity per unit volume while maintaining efficient protein utilization. The PER values obtained in this study were higher than those reported by Nguyen *et al.* (2021), where rearing juvenile red tilapia in a RAS system resulted in PER values ranging from 1.8 to 1.9. This proves that adequate oxygen levels in the water can maintain normal metabolic functions, including digestion and protein synthesis, and maximally utilize protein for growth (Nguyen *et al.*, 2021; Li *et al.*, 2020). According to Olusola & Nwanna (2014), a high protein efficiency ratio is due to the breakdown of protein into amino acids and its components, which makes protein absorption in fish more efficient. A higher protein efficiency ratio indicates that the feed is more efficient, as the protein content can be optimally utilized (Li *et al.*, 2012).

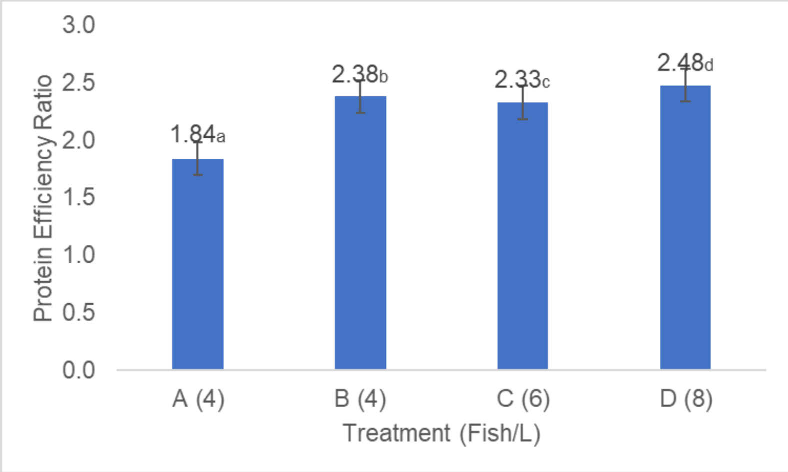

Figure 9. Protein efficiency ratio (PER) of juvenile red tilapia at different stocking densities in SAW and UFBs-RAS systems.

In contrast, based on the data obtained, the lowest Protein Efficiency Ratio (PER) was observed in the control treatment (SAW with a stocking density of 4 fish/L). This outcome is likely attributed to reduced nutrient absorption associated with elevated concentrations of ammonium chloride, which adversely affects feed intake. Foss *et al.* (2009) reported that increased ammonia levels can impair intestinal absorption efficiency, leading to a decline in the assimilation of digested nutrients. Consequently, this results in prolonged feed retention within the gastrointestinal tract, ultimately reducing the effectiveness of protein utilization for growth.

Feed conversion efficiency

The study's results (Figure 10) showed that the FCE ranged from 72 ± 3.7% to 96.5 ± 0.58%. ANOVA analysis indicated that the treatments had a statistically significant effect ($P<0.05$). Tukey's post hoc test revealed that treatment D achieved the highest FCE, which was significantly different ($P<0.05$) from treatments A and C, but not significantly different ($P>0.05$) from treatment B. In contrast, treatment A exhibited the lowest FCE and significantly differed ($P<0.05$) from all stocking density treatments in the UFBs-RAS system: treatments B, C, and D.

The Feed Conversion Efficiency (FCE) observed in the UFBs-RAS system under high oxygen (hyperoxic) conditions showed excellent results, especially in treatment D, which reached an FCE of 96.5 ± 0.58%. This value is much higher than the FCE reported by Shofura *et al.* (2016), ranging from 73.57% to 85.01%, and by Li *et al.* (2020), who recorded only 67% at an oxygen level of 5 mg/L (equivalent to 67% saturation at 28 °C). These findings support the results of Abdel-Tawwab *et al.* (2015), who found that tilapia grow better under high dissolved oxygen levels, especially when ammonia is well controlled. Saturated oxygen levels can increase feed intake (Duan *et al.*, 2011) and improve digestion and nutrient absorption by inducing a hypermetabolic state (Howerton, 2001). In contrast, low oxygen (hypoxic) conditions lead to stress, reduced feed intake, and slower growth (Sheng *et al.*, 2019).

Oxygen saturation in the SAW system is lower at level % 0%. It makes FCE (Li *et al.*, 2020) and limits feed intake

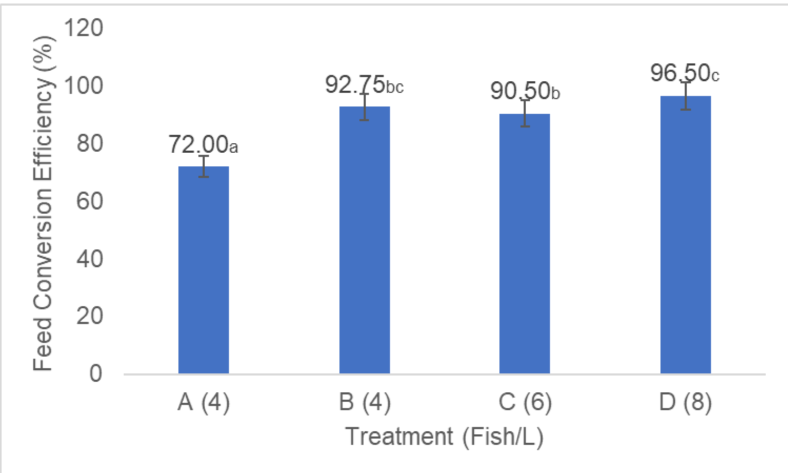

Figure 10. Feed conversion efficiency (FCE) of red tilapia juveniles at different stocking densities in SAW and UFBs-RAS systems.

(Buentello *et al*., 2000). Additionally, the SAW system's higher ammonia concentration (≥0.012 mg/L) further contributed to the reduced FCE. This is reinforced by the opinion of Briggs & Fing-Smith (2002) that elevated ammonia levels can lower appetite and shift nitrogen excretion toward less efficient forms such as urea. These factors combined suggest that high oxygen and low ammonia levels are essential for maximizing feed efficiency in intensive tilapia culture.

Coefficient of variation

In this study, the coefficient of variation was measured for weight. The results showed treatment A of 28.3 ± 0.01%, treatment B of 31.9 ± 0.02%, treatment C of 32.6 ± 0.02%, and treatment D of 33.70 ± 1.55%. Based on statistical analysis, treatment A was not significantly different from treatment B ($P > 0.05$), but was significantly different ($P < 0.05$) from treatments C and D. Meanwhile, treatments B, C, and D did not differ significantly from each other ($P > 0.05$).

Figure 11 shows that treatment A's diversity is lower than that of treatments B, C, and D. This is related to the low survival rate (65.83%), resulting in a very low stocking density. Thus, the level of competition among the fish becomes low. Unlike the conditions in the density treatment in the UFBs-RAS system, the SR in each treatment is relatively high, resulting in stronger competition among the fish in the cultivation medium. However, the treatment's overall CV value (31.9 to 33.7%) still indicates good quality. According to Almazan-Rueda *et al*. (2004), the uniformity level of the fish is still good if it is below 30%.

The finding in this study is that the maintenance of juvenile red tilapia in the UFBs-RAS system can improve fish diversity at high stocking densities of up to 8 fish/L. This refers to Borbossa *et al*. (2006), which indicates that tilapia juveniles raised at higher stocking densities (2 fish/L) show a high size variability. It results from competition for food supply (Borbossa *et al.*, 2006) and fish behaviour (Carbonara *et al.*, 2019). Furthermore, according to

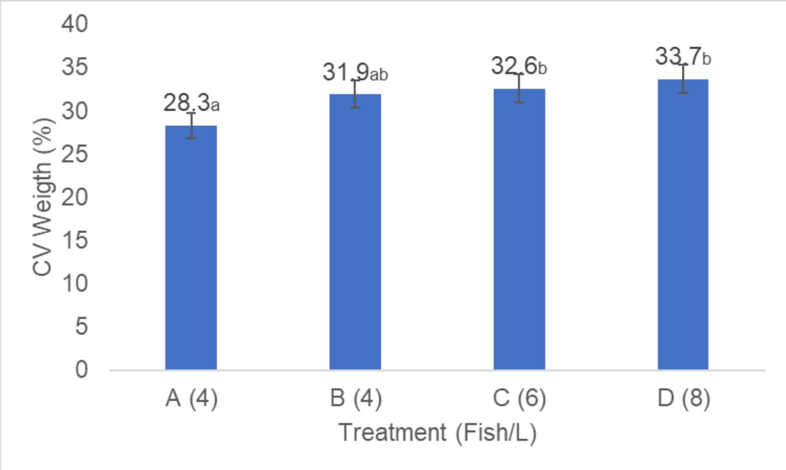

Figure 11. Weight variation of red tilapia juveniles at different stocking densities in SAW and UFBs-RAS systems.

Tibile *et al*. (2016), heterogeneous size variation might be linked to the formation of social hierarchies within each stocking density group, regardless of the adequacy of food availability and individual growth suppression. These results suggest that rearing using the UFBs-RAS system under normoxic conditions may be a promising strategy to improve size uniformity during the first nursing phase of tilapia hatchery production, thus enhancing product quality and market value.

CONCLUSION AND RECOMMENDATION

Conclusion

The present study demonstrated that the UFB-RAS system effectively maintained optimal water quality by increasing dissolved oxygen levels and reducing concentrations of ammonia and total dissolved solids (TDS), thereby enhancing the growth performance of red tilapia juveniles even at a high stocking density of 8 fish/L (twice as high as referred to Dawood *et al*. (2023). The achieved performance indicators included a survival rate of 98.75%, specific growth rate in total weight of 4.93 ± 0.062% per day, specific growth rate in total length of 3.88 ± 0.05% per day, protein efficiency ratio of 2.48 ± 0.02, feed conversion efficiency of 96.5 ± 0.58%, and a coefficient of variation in weight of 33.7 ± 1.2%. These results successfully addressed the research objective by confirming that the UFBs-RAS system enables optimal and sustainable juvenile production under intensive culture with a cost-effective and economically beneficial approach for fish farmers.

Recommendation

Based on the research results, it is recommended that UFBS-RAS be used to produce juvenile red tilapia at a high stocking density of 8 fish/L, which can improve productivity and efficiency. Furthermore, further research should be conducted with a higher density in the UFBs-RAS system.

AUTHORS' CONTRIBUTION

Conceptualizations, U.S., I.N.; methodology, U.S., I.M., I.N., A.R.A., R.G, and MAAM; validation, U.S, and I.M.; writing-original draft preparation, U.S., and I.N.; writing-review and editing, U.S., R.G., A.R.A., and I.M.; funding acquisition, U.S. All authors have read and agreed to the published version of the manuscript.

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