ORIGINAL ARTICLE

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Ultrafine bubble generator for oxygenation of Nile tilapia (*Oreochromis niloticus*) breeding tanks under recirculating water system

Utilização de um gerador de bolhas ultrafinas para oxigenação de tanques de criação de tilápia do Nilo (Oreochromis niloticus) *em sistema de recirculação*

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ABSTRACT: The objective of this work was to evaluate the use of an ultrafine bubble generator of own manufacture for oxygenation of Nile tilapia (*Oreochromis niloticus*) breeding tanks in a recirculating water system. The research was divided into two steps: 1) oxygen saturation test; 2) application of ultrafine bubble production technology for the breeding of Nile tilapia. In the first step, the water of a 2.0 m^3 test tank was completely deoxygenated and the ultrafine bubble generator was turned on for 60 min. In the second step, the generator was connected to the water recirculating system for breeding of Nile tilapia to compare the overall performance of this system with other under conventional aeration system. The ultrafine bubble generator could reach 100% oxygen saturation in the test tank (27.8 °C) in approximately 21 min and, at the end of 60 min, the concentration was 21.8 mg L^{-1} (277.52% saturation). The results showed significant difference ($p<0.05$) between the mean dissolved oxygen concentration in the treatment with ultrafine bubbles (9.80 ± 3.68 mg L^{-1}) and the treatment with conventional aeration (3.47 ± 0.88 mg L^{-1}). No significant difference ($p>0.05$) was found for the zootechnical performance parameters evaluated. The conclusion was that the ultrafine bubble generator is more efficient to maintain a high dissolved oxygen concentration in the recirculating water in Nile tilapia breeding tanks than the conventional aeration system.

KEYWORDS: Dissolved oxygen; nanobubbles; mechanical shear; hydraulic cavitation.

RESUMO: O objetivo da presente pesquisa foi avaliar a utilização do gerador de bolhas ultrafinas (fabricação própria) para oxigenação de tanques de criação de tilápia do Nilo em sistema de recirculação de água. A pesquisa foi dividida em duas etapas: 1) teste de saturação de oxigênio; 2) aplicação da tecnologia de produção de bolhas ultrafinas na criação da tilápia do Nilo. Na primeira, a água de um tanque teste (2,0 m^3) foi completamente desoxigenada e o gerador de bolhas ultrafinas acionado por um período de 60 min. Na segunda, o gerador foi ligado a um sistema de recirculação para criação de tilápia para comparar o desempenho geral desse sistema ao de outro no qual utilizou-se aeração convencional. O gerador de bolhas ultrafinas foi capaz de atingir 100% de saturação de oxigênio no tanque teste (27,8 °C) em aproximadamente 21 min e, ao final de 60 min, a concentração foi 21,8 mg/L (saturação 277,52%). Foi observada diferença significativa ($p<0,05$) entre a concentração média de oxigênio dissolvido no tratamento com bolhas ultrafinas (9,80 ± 3,68 mg/L) e o tratamento com aeração convencional (3,47 ± 0,88 mg/L). Não foi observada diferença significativa ($p>0,05$) para nenhum dos parâmetros de desempenho zootécnico avaliados. Pode-se concluir que o gerador de bolhas ultrafinas é mais eficiente em manter alta a concentração de oxigênio dissolvido em tanques de criação de tilápia em sistema de recirculação de água quando comparado ao sistema convencional de aeração.

PALAVRAS-CHAVE: Oxigênio dissolvido; nanobolhas; cisalhamento mecânico; cavitação hidráulica.

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INTRODUCTION

Ultrafine or nano bubbles are gas bubbles in aqueous solution that have diameters smaller than 200 nm (AGARWAL; NG; LIU, 2011). Nano bubbles present several remarkable physical, chemical, and mechanical properties, such as long residence time and stability (UCHIDA et al., 2011; USHIKUBO et al., 2010), large specific area, and great solubility of gases in water (AGARWAL; NG; LIU, 2011; AHMED et al., 2018; TAKAHASHI et al., 2003). The study of these characteristics have expanded the number of applications of ultrafine bubbles to several fields of science and technology: such as water treatment (ATKINSON et al., 2019; AZEVEDO; ETCHEPARE; RUBIO, 2017), animal and plant metabolism acceleration (DAHRAZMA et al., 2019; EBINA et al., 2013; IIJIMA et al., 2020; LIU et al., 2013), and aquaculture (GUNANTI; WULANSARI; KINZELLA, 2019; JHUNKEAW et al., 2021; KURITA; CHIBA; KIJIMA, 2017).

Nile tilapia (*Oreochromis niloticus*) is one of the most popular fresh water species in aquaculture, which has stood out in the Brazilian pisciculture as the most cultivated fish species (PEIXE BR, 2022). The success of tilapia in aquaculture can be attributed to the many characteristics of this species: higher tolerance to a wide range of water pH and toxic metabolite concentrations than most cultivated fish species; rusticity of management; fast growth; tolerance to densification; and good marketing acceptance (DALSGAARD et al., 2013; EL-SAYED, 2006; FAO, 2022). These attributes make tilapia an excellent choice for breeding in different system types, for example, bioflocs, aquaponics, and recirculating water systems (DANNER et al., 2019; FIMBRES-ACEDO et al., 2019; FLECKENSTEIN; TIERNEY; RAY, 2018).

Recirculating water systems is a viable technology in aquaculture for intensive cultivation of different species by minimizing pollution, maximizing production, and using less water when compared to other system types (BADIOLA; MENDIOLA; BOSTOCK, 2012; VAN RIJN, 2013). In recirculating water systems, as well as other aquaculture production systems, the dissolved oxygen (DO) is one of the most important environmental factors and its availability is usually the first factor that limits the load capacity in these systems (BADIOLA et al., 2018). Low DO concentrations affect the growth, survival, and health of fishes (ABDEL-TAWWAB et al., 2014; ESPINAL; MATULIĆ, 2019). Therefore, the incorporation of oxygen into the water through mechanical oxygenation/aeration provides adequate conditions for development and increases the stocks of fish biomass in breeding systems.

Traditional aeration methods are limited in terms of DO amounts that can be incorporated into the water. In addition to the use of atmospheric air as an oxygen source, the air bubbles generated by these systems do not present high stability and dissolution, which prevents them to reach great DO concentrations in the water (TAKAHASHI; CHIBA; LI, 2007; TEMESGEN et al., 2017; THI PHAN et al., 2020). Contrastingly, ultrafine bubbles are much more efficient at incorporating and stabilizing oxygen in the water (SENTHILKUMAR et al., 2018; USHIKUBO et al., 2010). Studies have shown that the use of ultrafine bubble technology can rapidly increase the water DO concentration and improve the performance of cultivated fishes and shrimps (EBINA et al., 2013; JAINONTEE et al., 2019; MAHASRI et al., 2018; RAHMAWATI et al., 2021). Results of researches have indicated that ultrafine bubbles have high potential for use in aquaculture, contribute to improvements in quality of the cultivation water, and increase the yield of aquaculture systems by increasing the fish stocking density. The application of the technology of ultrafine bubbles in aquaculture has been increasingly used around the world. However, published studies on the use of ultrafine bubbles in aquaculture systems are not found in Brazil. Applying the remarkable properties of these bubbles to the production of aquatic organisms could improve the Brazilian aquaculture by innovating the production methods and generating income and food safety.

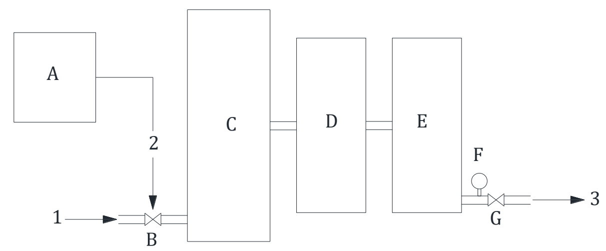
The main objective of the present work was to evaluate the use of an ultrafine bubble generator of own manufacture for oxygenation of Nile tilapia breeding tanks in a recirculating water system. In addition, the water saturation with ultrafine oxygen bubbles was evaluated.

MATERIAL AND METHODS

The research was developed at the Professor Raimundo Saraiva da Costa Aquaculture Station of the Federal University of Ceará (UFC), and approved by the Ethics Committee for Use of Animals (CEUA/UFC; protocol no. 6974061020). The study was divided into two steps: 1) oxygen saturation test; and 2) application of the ultrafine bubble production technology for breeding of Nile tilapia (*Oreochromis niloticus*).

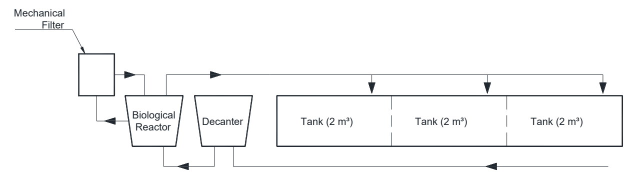
The saturation test was carried out under anoxic condition to show the capacity of the ultrafine bubble generator to incorporate oxygen into the water. This first step was carried out by using a concrete tank (test tank) with a useful volume of 2.0 m^3 and filled with clear water. A complete deoxygenation of the test water tank was carried out by using sodium sulfite (Na_2SO_3) at the rate of 10 mg L^{-1} for each 1 mg L^{-1} of dissolved oxygen (DO), combined with cobalt chloride ($CoCl_2$), as a catalyst, at 0.1 mg for each liter of water of the test tank (VINATEA; CARVALHO, 2007). After the DO concentration reach 0.0 mg L^{-1}, the water temperature was measured, the ultrafine bubble generator system was turned on and the saturation test was started. DO and temperature were measured every minute for 60 minutes with the aid of a multiparameter probe (Aquaread AP-800).

The ultrafine bubble generator used was a multistage generator of own manufacture, which operates according to the principles of mechanical shear and hydraulic cavitation (FIGURE 1).



(1) water inlet of the generator, (2) oxygen admission, (3) return of supersaturated water to the tanks, (A) oxygen concentrator, (B) gas suction system by the Venturi effect, (C) vertical axis water pump, (D) static mixer for water and gas, (E) macrobubble removal system, (F) pressure gauge, and (G) valve for pressure and flow controls.

Figure 1. Schematical representation of the multistage generator of ultrafine bubbles by mechanical shear and hydraulic cavitation used in the research.



Arrows represent the direction of water circulation between the units that compose the water recirculating system (aquaculture tanks – decanter – biological reactor – mechanical filter – aquaculture tanks).

Figure 2. Layout of the water recirculating system used in the second step of the experiment for breeding of Nile tilapia (*Oreochromis niloticus*).

In the second step, two forms of DO incorporation into the Nile tilapia breeding water (treatments) were evaluated: 1) conventional aeration carried out by using an air compressor connected to porous stones; 2) injection of oxygen through the ultrafine bubble generator.

This step of the research was developed in two independent recirculating water systems. According to the schematical representation presented in Figure 2, each system had three concrete rectangular tanks of approximately 2.0 m^3 (replications); a polyethylene circular decanter of a total volume of 500 L; a polyethylene circular biological reactor with a total volume of 500 L, containing 300 L of biological medium (BIOTECH 500); a mechanical pressurized filter connected to a submerged pump of 0.5 cv; a submerged pump of 10,000 L h^{-1} for water circulation between units; and their respective forms of incorporation of DO.

The dimensioning of the biological reactor of each system was carried out according to TIMMONS; EBELING; PIEDRAHITA (2009), considering: a mean ammonia removal rate of 0.4 g m^{-2} day^{-1}; an estimated final biomass of 55.0 kg; a daily feeding rate of 3.3%; and feed containing 32% crude protein and a specific surface of biological media of 500 m^2 m^{-3}, as informed by the manufacturer.

The maturation of the biological media was carried out before assembling the system: 600 L of the biological media were stocked in a 2.0 m^3 tank and maintained under strong aeration. Firstly, 5.9 g of ammonium chloride (NH_4Cl) were added to the maturation tank to reach a total ammoniacal nitrogen (TAN) concentration of 1 mg L^{-1}. Daily measurement of TAN concentration was carried out as needed, replenishing ammonium chloride to recover the concentration of 1 mg L^{-1}. The biological media were maturated when the TAN concentration reached 0.0 mg L^{-1} within 24 hours.

Forty-seven fishes with weights between 225 and 235 g, which were cultivated for 55 days, were stocked in each tank. They were fed four times a day (9:00 h, 12:00 h, 14:00 h, and 16:00 h) with a commercial feed containing 32% crude protein. The daily feed offer was calculated according to biometric results and the manufacturer's recommendations. The biometry was carried out every 14 days, measuring the weight and length of a fishes of a 10-fish sample from each tank, using a precision balance (0.01 g) and a caliper, respectively.

The biometry of all fishes stocked in the tanks and the evaluation of zootechnical parameters were carried out at the end of the experimental period, considering the mean initial weight (g); mean final weight (g); initial length (cm); final length (cm); initial biomass (kg); final biomass (kg); biomass gain (kg); survival (%); feed conversion factor (kg kg^{-1}); initial stocking density (kg m^{-3}); and final stocking density (kg m^{-3}).

DO concentrations and water temperatures were measured daily in the morning (8:00 h) and afternoon (16:00 h), with the aid of a multiparameter probe (Aquaread AP-800). TAN and nitrite were measured through colorimetric tests and pH was measured with a probe every five days (Aquaread AP-800). The concentration of non-ionized ammonia was obtained indirectly by crossing TAN, pH, and temperature data.

The data statistical analysis was carried out for water quality and zootechnical performance parameters by applying the student's t-test to compare the means of the two treatments. This analysis was carried out using the program Application of Statistical Analysis in the Biomedical Sciences (BioEstat, version 5.0) at 5% significance level (AYRES; AYRES JÚNIOR, 2007). The results expressed in percentages were transformed to arcsine for application of the statistical test.

RESULTS

The water temperature in the test tank remained constant (27.8 °C) during the first step. As shown in Figure 3, the dissolved oxygen (DO) concentration presented an almost linear result (R^2=0.9909) for 60 min. In this period, the DO concentration increased from 0.0 to 21.8 mg L^{-1}, which corresponds to a 277.52% saturation. Approximately 21 min were needed for the ultrafine bubble generator to reach 100% oxygen saturation, 7.8552 mg L^{-1} for the temperature of 27.8 °C.

Significant difference ($p<0.05$) was found between DO concentrations when comparing the oxygen incorporation systems (second step), either in the morning or afternoon period (TABLE 1). The saturations found for the ultrafine bubble generator system and conventional aeration system were, respectively, 9.84 ± 3.84 mg L^{-1} (129.6%) and 3.73 ± 0.89 mg L^{-1} (47.63%) for the morning period, and 9.74 ± 3.50 mg L^{-1} (129.8%) and 3.16 ± 0.75 mg L^{-1} (41.46%) for the afternoon period. Only the conventional aeration system presented significant difference ($p<0.05$) when comparing the periods (morning and afternoon) within the same system.

The water temperatures in the ultrafine bubble system in the morning (29.73 ± 1.03 °C) and afternoon (30.44 ± 1.01 °C) periods were statistically higher ($p<0.05$) than those in the conventional aeration system (28.04 ± 2.21 °C and 29.48 ± 0.93 °C, respectively) (TABLE 1). The temperature in the afternoon period was significantly higher ($p<0.05$) when compared to the morning period, in both systems.

The other water quality parameters evaluated showed that only pH and non-ionized ammonia (NH_3 - N) presented significant differences ($p<0.05$) when comparing the two systems. The means found for the ultrafine bubbles and conventional aeration systems were, respectively, 6.42 ± 0.28 and 6.82 ± 0.43 for pH, and 0.010 ± 0.009 mg L^{-1} and 0.043 ± 0.040 mg L^{-1} for NH_3 – N (TABLE 1).

No significant difference ($p>0.05$) was found for the zootechnical parameters evaluated (TABLE 2).

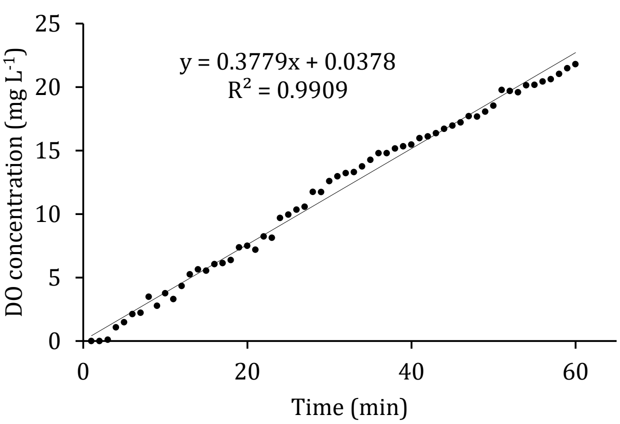


Figure 3. Increases in dissolved oxygen concentration over time during the oxygen saturation test.

Table 1. Means ± standard deviations of dissolved oxygen (DO), temperature (Temp.), hydrogen potential (pH), total ammoniacal nitrogen (TAN), non-ionized ammonia (NH_3 – N), and nitrite (NO_2^- – N) in the water for cultivation of Nile tilapia (*Oreochromis niloticus*) under different forms of incorporation of oxygen (ultrafine bubbles and conventional aeration).

Parameter	Ultrafine bubbles	Conventional aeration
DO – morning (mg L^{-1})	9.84 ± 3.84^{a}	3.73 ± 0.89^{Ab}
DO – afternoon (mg L^{-1})	9.74 ± 3.50^{a}	3.16 ± 0.75^{Bb}
Temp. – morning (°C)	29.73 ± 1.03^{Aa}	28.04 ± 2.21^{Ab}
Temp. – afternoon (°C)	30.44 ± 1.01^{Ba}	29.48 ± 0.93^{Bb}
pH	6.42 ± 0.28 ^{a}	6.82 ± 0.43^{b}
TAN (mg L^{-1})	4.23 ± 2.27	5.00 ± 2.30
NH_3 – N (mg L^{-1})	0.010 ± 0.009 a	0.043 ± 0.040 b
NO_2^- – N (mg L^{-1})	1.83 ± 0.98	2.29 ± 0.86

Means followed by different lowercase letters in the rows, or uppercase letters in the columns, are significantly different from each other ($p<0.05$).

DISCUSSION

The results found in the saturation test (first step) denote the high capacity of the ultrafine bubbles generator to solubilize and stabilize the water oxygen, rapidly increasing the dissolved oxygen (DO) concentration (21.8 mg L^{-1} after 60 min of operation of the generator). Other studies also showed fast incorporation of oxygen into the water by using nanobubbles; Ebina et al. (2013) found increases in oxygen concentration in distilled water from 7.7 mg L^{-1} to 31.7 mg L^{-1} after 30 minutes of operation of a nanobubble generator. In addition, Mahasri et al. (2018) used a nanobubble generator for 30 min and found DO concentration increases from 6.5 mg L^{-1} to 25.0 mg L^{-1}; and USHIKUBO et al. (2010) used a micro and nanobubble generator and found DO concentration of 36.9 mg L^{-1} in ultrapure water at 20 °C, using oxygen with 99.99% purity.

The differences in DO concentrations found in the literature are due to several factors, such as the ultrafine bubble generator characteristics (power, bubble generator method); water characteristics (temperature, organic matter) and volume used; and purity of the incorporated oxygen (%). In the present study, the oxygen concentrator used produces concentrated oxygen (93% ± 3%) from environmental air, and the test tank water temperature was 27.8 °C. Higher DO concentrations could be obtained in the saturation test if a higher oxygen purity was used and a lower water temperature was maintained, as it affects the oxygen solubility (BOYD, 1998).

Table 2. Means ± standard deviations of zootechnical performance parameters of Nile tilapia (*Oreochromis niloticus*) cultivated under different forms of incorporation of oxygen into the water (ultrafine bubbles and conventional aeration).

Parameters	Treatments	
	Ultrafine bubbles	Conventional aeration
Initial weight (g)	226.77 ± 55.35	230.82 ± 51.80
Final weight (g)	392.10 ± 93.53	370.21 ± 88.72
Initial length (cm)	24.12 ± 1.97	24.34 ± 1.83
Final length (cm)	28.16 ± 2.40	27.77 ± 2.19
Survival (%)	97.22 ± 21.19	95.74 ± 0.00
Initial biomass (kg)	10.66 ± 0.42	10.85 ± 0.51
Final biomass (kg)	17.65 ± 0.84	16.66 ± 0.94
Biomass gain (kg)	6.99 ± 0.57	5.81 ± 0.62
Feed conversion factor (kg kg^{-1})	1.84 ± 0.33	1.91 ± 0.38
Initial stocking density (kg m^{-3})	5.33 ± 0.21	5.42 ± 0.26
Final stocking density (kg m^{-3})	8.82 ± 0.42	8.33 ± 0.47

In the second step of the study, the mean temperature, pH, and NH_3 - N found in the environment for cultivation of Nile tilapia (TABLE 1) were adequate for the growth and survival of the species. The optimal conditions for the growth of tilapia are: temperature from 20 to 30 °C (DALSGAARD et al., 2013), pH between 6 and 9 (POPMA; MASSER, 1999), and NH_3 - N concentration below 0.05 mg L^{-1} (WAMBUA et al., 2021).

The lower pH found in the system with the use of ultrafine bubbles ($p<0.05$) was probably due to the high carbon dioxide (CO_2) concentration in the system. CO_2 accumulation in systems with minimum water exchange is very common, as the respiration of fishes and bacterial nitrification processes increase CO_2 levels in the cultivation environment. The system under conventional aeration presented greater water surface movement due to the intense presence of macrobubbles, which results in a higher escape of CO_2 to the atmosphere. However, the absence of agitation on the water surface in tanks with oxygenation through ultrafine bubbles results in a higher CO_2 accumulation in the water. CO_2 generates carbonic acid (H_2CO_3) in aqueous media, which is dissociated in H^+ ion, lowering the pH, according to the reaction: $CO_2 + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$ (TIMMONS; EBELING; PIEDRAHITA, 2009). It explains the lower pH found in the system using ultrafine bubbles.

The highest NH_3 – N concentration ($p<0.05$) found in the conventional aeration system (TABLE 1) can be attributed to the higher pH. The relative concentration of ammoniacal nitrogen forms (NH_3 – N and NH_4^+ – N) is directly affected by pH and temperature, whose increases raise the proportion of non-ionized ammonia (NH_3 – N) in the aqueous medium (RANDALL; TSUI, 2002). Jainontee et al. (2019) found lower pH and NH_3 – N in tilapia cultivation system with ultrafine bubble generator, as also found in the present study (TABLE 1).

Total ammoniacal nitrogen (TAN) and nitrite are toxic compounds that can promote histological and biochemical changes, affecting the growth and health of aquatic organisms (BRAZÃO et al., 2021; DOS SANTOS SILVA et al., 2018; MOLAYEMRAFTAR et al., 2022). TIMMONS; EBELING; PIEDRAHITA (2009) recommend concentrations below 3.0 mg L^{-1} for TAN and below 1.0 mg L^{-1} for nitrite (NO_2^- – N) in recirculating water systems for cultivation of tilapia. In the present study, the results found for these parameters were outside this range (TABLE 1) in both oxygen incorporation systems tested (ultrafine bubbles and conventional aeration). These results are higher than concentrations found in other studies using recirculation systems (NHI et al., 2018; WAMBUA et al., 2021). The biological reactors used in the present study were correctly dimensioned and maturated to meet the needs of the stocked fish biomass. Thus, some factor inherent to water quality affected the biological reactor efficiency, generating an accumulation of nitrogen compounds in the systems.

Dissolved oxygen (DO) is one of the most important water quality parameters and its availability is usually the first factor that limits the load capacity in recirculating aquaculture systems (TIMMONS; EBELING; PIEDRAHITA, 2009). The maintenance of an ideal DO concentration provides adequate conditions for growth of fishes, good performance of the biological reactor, and a greater fish biomass in the system (BADIOLA et al., 2018). When comparing the two oxygen incorporation forms, the results of the present study showed that the DO concentrations were greater in tanks with oxygenation through the ultrafine bubble generator (TABLE 1). The bubbles generated by the conventional aeration system were partly composed of macrobubbles, which have less stability and residence time, as they tend to rise quickly and burst at the water surface (TAKAHASHI; CHIBA; LI, 2007; TEMESGEN et al., 2017). Thus, macrobubbles have low gas dissolution rates (THI PHAN et al., 2020), which prevents the occurrence of high DO concentrations in the water. The nanometric size of bubbles generated in the ultrafine bubble generator system makes them highly stable due to their horizontal movement in aqueous solutions, which prevents them from rising to the water surface and bursting (SENTHILKUMAR et al., 2018; USHIKUBO et al., 2010). Ultrafine bubbles also have high gas dissolution rates, which promote higher DO concentrations in water. Thus, the ultrafine bubble generator system is more efficient to incorporate and stabilize oxygen in water than the conventional aeration system. It explains the higher DO concentration found in the system with ultrafine bubbles.

The use of ultrafine bubble technology efficiently provided oxygen to the fishes and increased DO concentrations above the saturation concentration in the tanks with the ultrafine bubble generator. However, the means of DO found for the conventional aeration system were lower than those reported in other studies that used recirculating water systems (FIMBRES-ACEDO et al., 2019; NHI et al., 2018). According to DALSGAARD et al. (2013) and MASSER; RAKOCY; LOSORDO (1992), DO concentrations should be maintained above 5 mg L^{-1} over the cultivation time for a satisfactory functioning of the recirculating water system. However, tilapia fishes are resistant to low DO levels (ROSS, 2000), tolerating DO concentrations of 3 mg L^{-1} (TIMMONS; EBELING; PIEDRAHITA, 2009).

The significantly different DO concentrations ($p<0.05$) between morning and afternoon periods (TABLE 1) in the treatment with conventional aeration were due to the significantly different water temperatures ($p<0.05$) between these periods. Increases in temperature reduce the water oxygen solubility (BOYD, 1998); thus, a higher DO concentration under lower temperatures is expected. However, despite the significant difference ($p<0.05$) between morning and afternoon temperatures in the treatment with ultrafine bubbles, the difference did not affect ($p>0.05$) DO concentrations. This finding denotes the long residence time and high stability of ultrafine bubbles in solutions, as reported by USHIKUBO et al. (2010) and MEEGODA; HEWAGE; BATAGODA (2018).

The system with ultrafine bubbles presents flotation of solids, which could be easily removed. This remarkable property was already reported in several works on water treatments (AGARWAL; NG; LIU, 2011; AZEVEDO; ETCHEPARE; RUBIO, 2017; GURUNG; DAHL; JANSSON, 2016; TEMESGEN et al., 2017). The use of ultrafine bubbles for producing aquatic organisms and increasing DO concentrations may contribute to improvements in water quality through the removal of suspended solids from the cultivation environment when integrated to a skimmer filter.

Tilapia fishes satisfactorily adapted to cultivation in both recirculating water systems with DO incorporation tested (ultrafine bubbles and conventional aeration), presenting survivals compatible with those reported in other studies (FIMBRES-ACEDO et al., 2019; OBIRIKORANG et al., 2019). Different results were found in some studies (EBINA et al., 2013; JAINONTEE et al., 2019; MAHASRI et al., 2018; RAHMAWATI et al., 2020), which reported improvements in the performance of fish and shrimp cultivated in a nanobubble system; this growth-inducing effect was not found in the present study.

Despite the lack of significant differences in the results found for the zootechnical parameters evaluated (TABLE 2), the maintenance of DO concentrations in the tanks indicated that a greater fish biomass can be stocked with the use of ultrafine bubble system (TABLE 1). This would not be possible in the conventional aeration system, as the DO concentrations observed in this system were close to the lower limit (DALSGAARD et al., 2013; MASSER; RAKOCY; LOSORDO, 1992). Therefore, the use of ultrafine bubbles in recirculating water systems may enable increases in gains of fish farming by increasing the fish stocking density and yield of the system. However, increases in stocking density should be followed by a correct dimensioning of other water treatment units, such as decanter and mechanical filter (removal of solids) and biological reactor.

Further researches evaluating longer Nile tilapia cultivation times may show possible positive effects of ultrafine bubbles on the zootechnical performance of this species. In addition, studies on tilapia at the finishing stage, when DO is usually a limiting factor, are recommended. Studies evaluating hematological and biochemical parameters of fishes cultivated in ultrafine oxygen bubble system are also important, as these analyses provide information on their health and physiological status.

CONCLUSIONS

Although improvements in the zootechnical performance were not found, the ultrafine bubble generator of own manufactured was efficient to incorporate and maintain a high dissolved oxygen concentration in the recirculating water system in Nile tilapia (*Oreochromis niloticus*) breeding tanks.

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