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High-rate algal ponds for improved dissolved oxygen supply for African Catfish (*Clarias gariepinus* Burchell, 1822) culture: A preliminary study

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Abstract
Low dissolved oxygen (DO) concentration is a major water quality challenge limiting the survival and performance of farmed fish, causing stress and leading to slow growth, and greater susceptibility to diseases, consequently resulting in low fish yields. This study investigated the application of a high-rate algal pond (HRAP) technology to improve DO concentration levels and supply for African catfish culture. Fish tanks were supplied with either DO-rich water from the HRAP mixed liquor (HRAPL) or DO-poor river water (RW). Each tank was stocked with 30 fingerlings of African catfish of average weight of 2 g. Growth performance parameters, fish yield, and survival were monitored fortnightly for three months from 23rd April to 16th July 2023. Results revealed significantly higher fish growth performance, yield, and survival in HRAPL-fed tanks than in RW-fed tanks. These results suggest the potential use of the HRAP system in enhancing DO concentration level and supply for improved fish growth in aquaculture production systems.

Keywords: African catfish culture, aquaculture, DO concentration, growth performance, high-rate algal pond system

Introduction

Fish remains a relatively more accessible source of household animal protein supply in Uganda and elsewhere, which provides a wide range of essential nutrients, and accounts for nearly 17% of the global population's intake of animal protein, as documented by The State of Food Security and Nutrition in the World [1]. Nonetheless, the sharp declines in capture fisheries production have exposed livelihoods in rural communities to food insecurity and malnutrition since fish from the wild used to be the primary source. Accordingly, a reported 11.7% of the global population faces food insecurity at severe levels [1]. Aquaculture has now been established as a means of supplementing the supply of fish supply from capture fisheries [2, 3], and in many cases has become the mainstay for fish supply.

In Uganda, small-scale fish farmers dominate the aquaculture industry, utilizing earthen ponds as major production systems. To meet the high fish demand, fish ponds are characterized by high stocking densities of African catfish (*Clarias gariepinus*) as one of the major aquaculture fish species adopted by small-scale fish farmers, a situation- attributed mainly to the species' fast growth, omnivorous feeding regime, and high tolerance to poor water quality [4, 5]. However, one of the leading problems associated with overstocked ponds is the deterioration of water quality including ammonia and organic matter build-up due to leftover feeds and fish excreta. Recent studies revealed that poor water quality is one of the factors limiting the growth and the consequent poor yield of the aquaculture industry [6, 7]. One of the critical water quality parameters limiting enhanced aquaculture productivity in ponds is dissolved oxygen (DO) concentration. In overstocked ponds, high DO concentration is required for nitrifying bacteria to offset the toxic ammonia, and mineralization of accumulated organic matter and algae [8]. Also, DO levels rise during daylight hours when photosynthesis occurs and decrease at night when respiration takes up most of the DO produced through photosynthesis in the day, dropping by 1 to 3 mg/L at night.

Although African catfish is known to survive under very low DO concentrations (0-3mg/l) attributed to possession of fully developed arborescent organs, which aids in breathing atmospheric oxygen [9], it has been established that low DO levels are associated with stress in cultured fish leading to poor appetite, slow growth, and greater susceptibility to diseases, and eventual mortality that consequently results in low fish yields [10]. Thus, studies recommend maintaining DO levels at 5 mg/l for optimal fish growth performance and health [11-13].

As a mitigation measure, several aeration devices are applied to prevent nighttime DO levels from falling below the critical level for African catfish of 3 mg/L. These include paddle wheel aerators, pump-spray aerators, vertical pump aerators, and diffusers to mention a few. Among the pond aerators, electrically powered paddlewheel aerators are commonly used by African catfish producers attributed not only to their portability but also to their high impact on the pond surface that rapidly increases DO due to their significant power (up to 1.7kg of oxygen per kWh) [14]. However, the requirement for electrical energy in rural Uganda and elsewhere in Africa may hinder the application of electrical paddle wheels as DO enhancers by rural fish farmers where Ingrid's electrical energy is erratic or absent. Additionally, the rapid movement of water by paddle wheels could impart stress on fish.

This study therefore aims to evaluate means of enhancing water quality in terms of increasing DO concentration using the high-rate algal pond (HRAP) technology on the growth performance and survival of African catfish. The HRAP technology application includes a solar-powered paddle wheel driven propeller that enhances the DO absorption in the pond water. HRAPs are shallow, paddlewheel-mixed open raceway lagoon-based systems that are traditionally utilized to maximize wastewater treatment by creating optimal conditions for algal growth and oxygen production [15]. Like in conventional ponds, HRAPs rely mainly on the symbiotic association between bacteria and microalgae utilizing sunlight as a major source of energy to remove pollutants from wastewater [16]. Microalgae uptake nutrients, particularly Nitrogen and Phosphorus, and through the process of photosynthesis, they supply oxygen to bacteria for use to mineralize organic matter. In turn, microalgae utilize carbondioxide produced by bacteria during respiration for growth [17].

In the present study, river water was employed as an influent for the HRAP, which was constantly mixed by the paddle wheel, allowing absorption of oxygen in the pond water, not only from algal productivity but also atmospheric aeration by the paddle wheel activity. Despite this theory, there is a paucity of information to elucidate the potential of HRAP water quality to support fish growth. It is therefore against this background that the present study was proposed. The intention was first to ascertain if HRAP water quality was within limits recommended for reuse in fish culture facilities and, second, to establish whether HRAP pond water quality could support fish growth. Results of the study are discussed in terms of the potential of HRAP mixed liquor (HRAPL) water quality to promote fish growth and survival with particular emphasis on its ability to improve dissolved oxygen concentration.

Materials and Methods

Fish tank configuration and operation

The study was conducted using three laboratory-scale circular plastic tanks (Diameter 0.65 m × Height 0.57 m) made of high-density polyethylene (HDPE) material. The tanks were positioned outside, under ambient conditions at the Faculty of Natural Resources and Environmental Science, Namasagali Campus, Busitema University, Uganda (1° 0' 27″ North, 32° 56' 59.99″ East) and operated for 12 weeks from April to July 2023.

Two (2) tanks were manually fed with HRAPL while one tank (control) was fed with RW up to a depth of 0.3 m, a resultant volume of 0.1 m^3 (Figure 1). Each tank was stocked with 30 *C. gariepinus* fingerlings of average weight 2 g. The stocked *C. gariepinus* were fed three times daily on formulated fish feeds purchased from Koudijs Uganda SMC Limited. 50% of the water from fish tanks was withdrawn daily and replaced with either fresh HRAPL or RW.

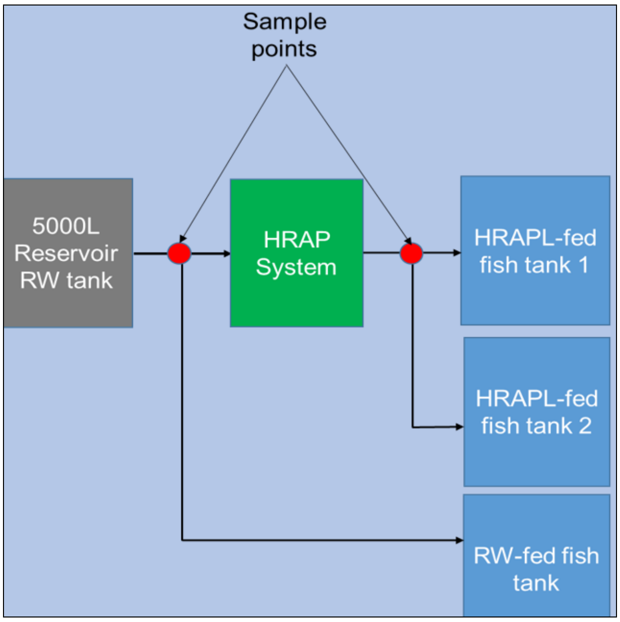

Fig 1: Schematic process flow and experimental set-up used to assess the growth performance of *C. gariepinus* in tanks fed with either HRAPL or RW established at The Faculty of Natural Resources and Environmental Sciences, Namasagali Campus, Busitema University, Uganda

Water quality sampling and analysis

Physico-chemical water quality parameters of the HRAPL and RW were routinely measured on-site before introduction into the fish tanks and these included: pH, temperature, and DO and these were all determined using a multi-parameter probe model HANNA H198194.

Monitoring African catfish growth

African catfish growth was monitored fortnightly over a twelve (12) weeks growth period from April until the harvesting time in July 2023. The growth performance of fish in terms of absolute growth (body weight gain), absolute growth rate, and specific growth rate were determined over time; and these were computed based on body weight at harvest using the formulae as presented below:

Absolute growth (AG) = W_2-W_1,

Absolute growth rate (AGR) = $(W_2-W_1)/t$

Specific growth rate (SGR) = $((\ln W_2-\ln W_1)/t) \times 100$,

Where, W_I = initial weight (g), W_2 = final weight (g), t = time (rearing period), and ln = natural logarithm.

Fish yield, however, was expressed as total biomass at harvest while survival rate was computed using the formula:

Survival rate (SR) = (N_a/N_f) x 100; where; N_a = Number of adult fish at harvest and N_f = number of fingerlings at stocking.

Statistical Analysis

Data were analyzed using the statistics function in Sigma Plot version 11 (Systat Software Inc., San Jose, CA). Data for the two tanks supplied with HRAPL were pooled and presented a single mean ± Standard error (SE). Where necessary, results were analyzed by one-way analysis of variance and significant differences between measurements for each treatment determined at a significant level of 5%.

Results

Environmental water quality parameters

Physico-chemical parameters of water quality in the HRAPL and RW used to feed the fish tanks recorded during the study period are presented in Table 1. The mean water quality for all parameters in the HRAPL is significantly higher than in RW ($p<0.05$) except temperature.

Table 1: Physico-chemical water quality composition of HRAPL and RW fed in African catfish fish tanks

Parameter	HRAPL		RW	
	Range	Mean + SE	Range	Mean + SE
Temperature (°C)	23.0-26.11	24.59±0.11 (68)	24.99-27.07	26.37±0.07 (68)
DO (mg/L)	4.75-5.98	5.19±0.05 (68)	4.01-5.21	4.63±0.04 (68)
pH	8.99-11.11	9.63±0.06 (68)	7.01-8.91	7.65±0.05 (68)

HRAPL = high-rate algal pond mixed liquor; RW = river water. Values are mean ± SE. Numbers in the parenthesis represent number of data used to calculate the means

Growth performance of African catfish

Figure 2 shows changes in the body weight (absolute growth) of the experimental stock of African catfish over the 12 weeks monitoring period in tanks fed with HRAPL and RW while Table 2 provides a summary of all growth parameters, fish yield and survival rate.

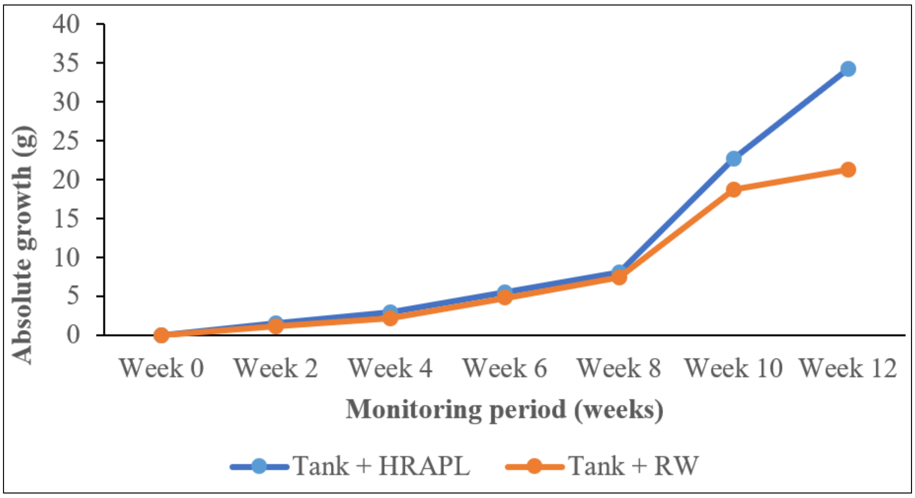

Fig 2: Change in body weight (absolute growth) of African catfish over the 12 weeks monitoring period in tanks fed with HRAP mixed liquor (HRAPL) and River water (RW)

Table 2: Growth performance of African catfish in tanks fed with either HRAPL or RW

Parameter	Fish tank +HRAPL	Fish tank + RW
Mean weight of stocking (g)	2.0±0.2 (60)	2.0±0.2 (30)
Mean weight of harvest (g)	36.3±3.7 (30)	23.3±0.02 (15)
Absolute growth (g)	34.3	21.3
Absolute growth rate (g/d)	0.5	0.3
Specific growth rate (%)	4.3	3.6
Fish yield (g/m^2)	2682.4	1909.4
Survival rate (%)	91.7	90.0

HRAPL= HRAP mixed liquor; RW = river water. Weight at stocking and harvesting values are mean ± SE. Numbers in the parenthesis represent the number of data used to calculate the means

Results indicate that HRAPL-fed tanks exhibited considerably higher absolute growth, absolute growth rate and specific growth rate at the end of the monitoring period than RW-fed tank. Furthermore, higher fish yield of up to 2682 g/m^2 and survival rate of 91.7% was attained in the HRAPL-fed tanks than in the RW-fed tanks (Fish yiel: 1909 g/m^2 and survival: 90.0%).

Discussion

Environmental water quality parameters

Monitoring the water quality of a water source for use in aquaculture production systems is vital since poor water quality reduces fish growth and survival and may result in fish kills. Low DO levels in pond water may also result in poor health and disease outbreaks [10]. Water quality parameters of aquaculture production systems investigated in the present study included temperature, pH, and DO as these significantly influence the growth performance and survival of the culture of African catfish [18]. The recommended water quality parametric levels for African catfish culture are as follows: 26-30 °C for temperature [19], 5-6 mg/L for DO concentration [20], and 6.5-8.5 for pH [21]. Thus, the water quality recorded in the HRAPL of 24.59±0.11°C, 5.19±0.05 mg/L, and 9.63±0.06 for temperature, DO and pH respectively are not significantly different from acceptable ranges for *C. gariepinus* culture. However, while the mean temperature (26.37±0.07 °C) and pH (7.65±0.05) recorded in RW are within the acceptable range for African catfish culture, the mean DO (4.63±0.04 mg/L) is below the recommended value (Table 1). Indeed, the mean DO concentration obtained in the present study in the HRAPL is significantly higher than that of RW p<0.05. This suggests the role of the paddle wheel in replenishing oxygen in the HRAP, which is accomplished by constantly mixing water thus, exposing algae to sunlight that improves photosynthesis and the consequent oxygen production [15]. Furthermore, aerators such as paddle wheels enhance the interfacial area between air and water, enhance the oxygen transfer rate, and provide better water circulation [22]. In this study, higher DO concentration was observed in the HRAPL mixed liquor than RW, which suggests that HRAP technology is a sustainable biotechnology for enhanced water supply for the culture of African catfish and other farmed fishes, as a moderator of pondwater for increased oxygen supply as a means of improving fish growth performance and aquaculture productivity. The HRAP biotechnology off-sets DO challenges inherent in pond fish culture systems.

Effect of DO concentration on the performance of African catfish

The performance of African catfish was assessed based on absolute growth, absolute growth rate, specific growth, survival rate, and yield using HRAPL and RW. Results revealed that tanks supplied with HRAPL resulted in better performance of African catfish for all growth parameters than the tank fed with RW (control) (Table 2). This difference in performance can partly be attributed mainly to the higher DO concentration recorded in the HRAPL than RW (Table 1). A study for instance reported that DO concentration significantly affects fish growth since DO levels below 5-6 mg/L in the water column result in fish hypoxia [23]. Thus, hypoxia is known to be the primary cause of stress, poor appetite, and infection in fish. The mean DO concentration of 5.17±0.06 mg/L recorded in the present study in tanks fed with HRAPL is within the range of 5-6 mg/L reported for optimal growth of aquatic organisms [23]. While African catfish can survive a DO concentration of below 3 mg/L, it has been pointed out that DO levels below 5 mg/L expose fish to stress leading to reduced growth [10, 24]. Thus, the tank fed with RW exhibited lower DO concentrations throughout the research period, ranging from 4.00 to 5.21 mg/L (4.63±0.04 mg/L). These values indicate suboptimal DO concentration for African catfish [25].

It is reported that DO is required for fish for metabolic processes such as respiration to generate the energy needed for various activities, such as growth, swimming, reproduction, etc. [26, 27]. As the DO concentration reduces, respiration and feeding activities also decrease inducing stress in fish, consequently, the growth rate is reduced [28-30] as observed in the tank fed with RW (Table 2). We suggest that the higher growth performance for African catfish observed in tanks fed with HRAPL than that supplied with RW is due to the significantly higher DO concentration recorded in the tanks fed with HRAPL than in the tank supplied with RW. Indeed, DO content is highly dependent on temperature hence, there was a negative correlation recorded between DO and water temperature [31]. Thus, results of the present study revealed that at lower temperatures recorded in the HRAPL than RW, correspondingly higher DO concentration was recorded (Table 1).

Conclusion

The findings of this study revealed that water quality for all monitored parameters from an HRAPL was within the recommended range suitable to support African catfish growth. The growth performance of this species in tanks fed with HRAPL in comparison to RW-fed tanks, showed that the African catfish in HRAPL-fed tanks benefited from the high DO concentration. Consequently, HRAPL-fed tanks revealed better growth performance, survival, and yield of African catfish than RW-fed tanks, which is attributed to the higher DO concentration recorded in the HRAPL than RW. These results suggest the future potential application of HRAP biotechnology for increasing aquaculture production and productivity of African catfish.

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