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RESEARCH

Watery yucca (*Yucca schidigera*) additions and biofloc as closed water systems: an assessment of their effects on reproductive efficiency, biochemistry and blood gases, and fry performance of Nile tilapia (*Oreochromis niloticus*)

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Abstract
Global water scarcity is a growing concern, prompting aquaculture specialists to seek techniques for prolonged water quality maintenance. This study conducted an 84-day spawning trial of Nile tilapia broodstock followed by a 45-day fry rearing trial under four treatments: control A (CA, unchanged water), control B (CB, 50% weekly water change), yucca (unchanged water with daily *Yucca schidigera* extract addition), and biofloc. Broodstock were distributed in three replicates per treatment (1 male:3 females) in 1.5-m^3 tanks. Fish were fed a 30% protein commercial diet at 1% biomass. Fecundity indices, gonadosomatic index, and blood sex hormones were measured 20 days post-trial initiation. Fry were collected and reared in separate tanks, fed 40% protein diet. Results showed that the biofloc group, followed by yucca and CB, exhibited the highest levels of blood sex hormones, improved liver and kidney functions, enhanced blood oxygen saturation, and lower ammonia and carbon dioxide levels. These factors contributed to higher reproductive efficiency and fry production with superior growth performance and survival rates compared to CA. Nile tilapia broodstock spawned under a biofloc system or an unaltered water system with *Y. schidigera* extract additions produced higher quality fry and demonstrated better physiological status and reproductive efficiency. Furthermore, *Y. schidigera* can complement biofloc technology, potentially improving growth and immune status of farmed fish through enhanced water quality parameters.

Keywords Biofloc · Broodstock · Blood gases · Reproduction efficiency · Water physiochemical

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Extended author information available on the last page of the article

Introduction

Aquaculture has become a vital industry in recent years, due to supply the increasing global demand for fish, to support economic growth, and to maintain human health (WHO, 2023; Maulu et al. 2021). Egypt is now the aquaculture powerhouse of Africa, producing 71% of the entire continent's farmed fish (Cristiano et al. 2023), with Nile tilapia (*Oreochromis niloticus*) being one of the most important species cultivated (Khalil et al. 2022). Despite this tremendous development, the future of this sector has become uncertain due to a variety of challenges primarily associated with climate change and water scarcity (Adeleke et al. 2020; Khalil et al. 2021). Because of water shortages, fish farmers are not allowed to use fresh irrigation water and instead have to use treated wastewater that is sometimes less clean than the water already in fish ponds. Additionally, water quality deteriorates as a result of feed residues and metabolic compounds derived from fish effluents, including carbon dioxide, ammonia nitrogen, nitrite, and nitrate (Gendel and Lahav 2013). Therefore, maintaining water quality for as long as possible and prolonging water change intervals are very important factors in the sustainability of aquaculture in Egypt (Abdel-Aziz et al. 2023).

To address these challenges, researchers have explored various strategies, including the use of water additives and modern aquaculture systems. Previous studies have shown that these approaches may be promising solutions to overcome water scarcity or pollution issues. Among these aquatic additives, yucca (*Yucca schidigera*) have received much attention in the aquaculture industry due to their natural origins. Yucca (*Yucca schidigera*) is a medicinal plant that contains many bioactive components, including steroidal saponins and polyphenolics such as resveratrol and yuccaols (Piacente et al. 2005). The steroidal saponins are known for their anti-inflammatory properties, while polyphenolics like resveratrol exhibit strong antioxidant effects, potentially enhancing the fish's immune system. Phytoandrogens such as steroidal saponins have exert functional effects similar to testosterone in animals, elevating male reproductive characteristics (Turan and Akyurt 2005). Furthermore, El-Deep et al. (2020) reported that yucca as feed or water additives can improve water quality by reducing levels of unionized through increasing protein metabolism in the fish body, leading to a reduction in ammonia excretion and then improvement in broodfish performance (Santacruz-Reyes and Chien 2010; Yu et al. 2015; Fayed et al. 2019). Additionally, applying modern systems is one of the means to overcome the problems of water shortage and quality deterioration. In recent years, biofloc technology (BFT) has been widely applied. BFT is an aquaculture system with zero or minimal water exchange, aggregating the microorganisms' (bacteria, microalgae, protozoa, and others of organic particles) form in the water column which is rich in important nutritional compounds for broodfish and the newly hatched larvae (Avnimelech 2009). Several studies showed that BFT improved the reproductive performance of tilapia and African catfish (*Clarias gariepinus*) in terms of increasing the number of fry produced and the relative fecundity (Ekasari et al. 2015, 2016). Where, floc provides vitamins, antioxidants, and essential amino and fatty acids which can fortify brooder reproduction (Kuhn et al. 2009). These nutrients are necessary for supporting gonadal maturation and high egg quantity and quality (Dabrowski and Ciereszko 2001). Additionlly, BFT significantly improved the water quality of aquaculture media leading to enhance the chances of procreation and provides the appropriate environment for hatching and development of larvae (Avnimelech 2007).

Our research is the first to compare the reproductive efficiency and physiological status of Nile tilapia broodstock, as well as the growth rates of their larvae, under unchanged

water systems using both biofloc technology and *Yucca schidigera* as water additives. So this study aimed to provide crucial insights into sustainable aquaculture practices that can maintain productivity while addressing water scarcity challenges in regions like Egypt, potentially offering innovative solutions for the future of aquaculture in water-stressed environments.

Materials and methods

Ethical agreement

All institution recommendations of the National Institute of Oceanography and Fisheries (NIOF, Egypt) Committee for Ethical Care and Use of Animals/Aquatic Animals were followed by the authors, and the experimental procedures were approved with the code number (NIOF-AQ1-F-24-R-023). All study practices (fish handling, sampling, euthanasia, etc.) rigorously followed the ARRIVE guidelines, ensuring that the research approach is consistent with recognized ethical standards and preserves the well-being of the experimental animal.

Location of work and facilities

This study was conducted indoors at the Wet Laboratory of Aquatic Research Station, National Institute of Oceanography and Fisheries (NIOF) in Fayoum, Egypt. The laboratory includes 16 fiberglass tanks, each with a volume of 1.5 m^3. It is equipped with two blowers (2 hp) connected to a network of plastic pipes. The air supply is controlled through valves and air distributors. This laboratory was also equipped with a large tank with a capacity of 10 m^3 to store water before use.

Broodstocks and experimental steps

Broodfish of *Oreochromis niloticus* were purchased from a private fish farm in Shakshouk (Fayoum) located 15 km from the work site. Broodstock was transferred in an oxygenated tank filled with water (1 m^3) and then placed in a tank for disinfection and pathogen prevention with formalin at a concentration of 50–150 ppm for 3 h. Subsequently, females and males were placed separately in two fiberglass tanks (1.5 m^3) which were continuously aerated to acclimate the fish to the laboratory conditions for 2 weeks.

Brood fish were fed a commercial diet (30% protein, 5.73% fat, 4.33% fiber, and gross energy 4.00 kcal/g—Grand Co. for manufacturing fish feed Damietta-Egypt) at a rate of 2% of biomass daily at 9:00 a.m. and 4:00 p.m. during the acclimation phase. During the experimental phase, which continued for 84 days, fish were fed at a rate of 1% of biomass. At the end of the adaptation period, 12 tanks were filled with dechlorinated tap water and provided with continuous aeration. Then, 24 males with an initial weight of 140.63 $\pm$ 1.62 g and 72 females with an initial weight of 109.98 $\pm$ 1.48 g (SE) were randomly selected and distributed among 12 tanks at a sex ratio of 1 male:3 females (2:6 per tank).

Design and water additives

Four treatments were performed in triplicate as follows: (1) control A (CA): fish were reared under unchanged water; (2) control B (CB): water exchange rate of 50% of tank volume weekly; (3) yucca treatment (yucca): fish were reared under unchanged water with the addition of a commercial yucca extract (AQUA-YUCCA) at a rate of 0.5 mL/tank daily; and (4) biofloc treatment (biofloc): fish were reared under a biofloc system. AQUA-YUCCA (*Yucca schidigera* extract 100%) was manufactured by Falcon Egypt for Canal Aquacure Company. In the biofloc treatment (BFT), molasses was used as a source of carbon with a C:N ratio of 10:1 (Avnimelech 1999). Molasses of El Bawadi Manufacturer, Egypt, were used according to calculations of Craig and Helfrich (2002) and Piedrahita (2003) and they reported that 16% of dietary protein is nitrogen. And 75% of total feed nitrogen ends up as water. Also, 50% of dry matter for most organc compounds is carbon (De Schryver et al. 2008).

Water measurements and management

Tap water was the source of water used in this trial. It was stored for 48 h before use to volatilize the chlorine. Water temperature was measured and recorded daily using a centigrade thermometer. Dissolved oxygen and pH were determined weekly using a Tintometer Group® (pH/OPR, DO, CD/TDS; Nr., 00724200. Germany 01/16). Water ammonia, nitrite, and nitrate were analyzed every 15 days using a spectrophotometer model (LKB Biochrom UV–visible spectrophotometer) according to the Nessler method.

An Imhoff cone was used to determine the biofloc volume. When the volume reached 20 mL, aeration was stopped, and a siphon process was performed to remove wastes and feed or faces residuals. The lost water was then replaced to return the tanks to their normal volume. Simultaneously, siphoning was also performed for the other treatments, and the lost water was replaced.

Sampling

After 20 days from the start of the trial, one replicate (2 males and 6 females) per treatment was sacrificed and placed in a 100-L ventilated tank and immmersionly anesthetized with clove oils at a dose of 50 µL/L for 5 min (El-Dakar et al. 2021) for blood sampling and gonad collection to determine levels of blood sexual hormones, fecundity, eggs diameter, and gonad-somatic index (GSI) as indicators of the fish status before mating, ovulation, and spawning. This procedure was repeated at the end of the experiment with a random fish sample (4 males and 4 females) per treatment for evaluating the plasma biochemical parameters and blood gases.

Blood was withdrawn from the caudal vein using a 3-mL syringe. The collected blood from males or females per treatment was divided into three tubes (3 mL blood of each): heparinized tubes for estimating the blood gases, ethylenediaminetetraacetate (EDTA) tubes for analyzing the blood ammonia, and tubes without anticoagulants that were allowed to clot for 30 min at 4 °C. The latter were then centrifuged at 3000 rpm for 10 min to obtain serum, which was maintained at −20 °C for biochemical analysis.

Serum biochemical assay

Blood sexual hormones Sex steroid hormones were evaluated using the enzyme-immunoassay technique with commercial ELISA kits. Luteinizing hormone (LH) and progesterone (P4) were quantitatively determined according to the methods described by Rinchard et al. (1993) and Alvarado et al. (2015). Testosterone, follicle-stimulating hormone (FSH), and estrogen were measured using a radioimmunoassay method described by Foster and Dunn (1974).

Glucose, liver, and kidney functions Serum glucose was determined using the colorimetric method described by Tietz et al. (1995). Aspartate aminotransferase (AST); alanine aminotransferase (ALT); creatinine, urea, and uric acid were measured according to the methods of Reitman and Frankel (1957) and Sallam et al. (2024) using kits from the Egyptian Company for Biotechnology, Egypt.

Blood gases assay

Blood ammonia (NH_3) was determined by the kinetic enzymatic method with glutamate dehydrogenase using commercial kits (Catalog No., 220–001) from the Egyptian Co for Biotechnology-Spectrum Diagnostics (S.A.E.), Cairo, Egypt. An ABG electrolyte analyzer (Demska-Zakę´sr ST2000OC) was used to assess blood pH, partial pressure of carbon dioxide (pCO_2), partial pressure of oxygen (pO_2), oxygen saturation (sO_2), and concentration of bicarbonate ions (HCO_3-) according to Becker et al. (2012).

Harvesting and raising fry

Fry were collected from the broodstock tanks as soon as they emerged, then counted and weighed, and their length was measured. They were then transferred to an equipped tank with adequate aeration in the same laboratory. Eight fiberglass tanks (1.5 m^3) were prepared for a rearing experiment using these fry, with the same treatments as the hatching experiment. The tanks were washed and sterilized thoroughly, filled with dechlorinated water, and provided with aeration. The fry of the first hatching batch was randomly distributed in tese tanks a week after collection and had an averge initial weight of 0.014 ± 0.003 g.

A floc starter was added to the biofloc treatment tanks, consisting of 10 L water from the broodstock biofloc tank mixed with 200 mL of molasses and 50 g of feed containing 40% protein and 50% yeast per m^3 of water. This mixture was added to the tanks with heavy aeration 1 week before stocking the fry. Fry were randomly distributed at a stocking rate of 250 fry/tank and subjected to the same treatments as the broodstock for 45 days. Fry were fed a commercial diet (45% protein, 1.48% fat, 1.80% fiber, and 3.45 kcal/g of gross energy) of Agri-mix Co. 6 Industrial Zone, Sadat City, Egypt. Feeding was four times daily (9 a.m., 12 p.m., 2 p.m., and 4 p.m.) with a level of 20% of biomass, which gradually decreased to 7% of biomass. At the end of this trial, a random sample from each replicate was taken and weighed to calculate growth performance.

Estimations

Reproductive indices

Absolute fecundity = mean number of eggs at each spawning per female (Murua et al. 2003).

Relative fecundity = mean number of eggs at each spawning per female body weight (g) (Qadri et al. 2015).

Egg diameter: A sample of eggs was taken from each female using a cannula and fixed in 5% formalin, then placed on a slide for examinationusing an eye-piece micrometer with a binocular microscope at a power magnification of 10 × following the method described by Budi et al. (2020).

Gonad-somatic index (GSI %) = [gonad weight (g)/somatic weight (g)] × 100.

Performance calculations of fry

Weight gain (g) = final weight (g) − initial weight (g).

Daily growth rate (g/day) = weight gain (g)/experimental period (days).

Specific growth rate (%/day) = [(ln final weight − ln initial weight)/period in days] × 100, where ln is the natural logarithm.

Feed conversion ratio (FCR) = dry feed intake (g)/weight gain (g).

Survival rate (SR %) = (Number of fish survived at the end of the experiment/Number of fish at the beginning) × 100.

Statistical analysis

Data were analyzed using SPSS Statistical Package Program version 23. A one-way analysis of variance (ANOVA) was performed, followed by Tukey's multiple comparison test at a significance level of $P < 0.05$. The data are expressed as mean ± standard error (SE).

Results

The results show the superiority of the biofloc and yucca groups in most of the study's paramaters of reproductive performance or fry growth compared to the control groups. The following is a detailed list.

Water quality parameters

Table 1 presents the water quality values, which show significant differences in all parameters except temperature between the control aeration (CA) and other treatments. The CA group exhibited notably elevated levels of pH, total ammonia, and nitrate compared to the

Table 1 Water physiochemical parameters of Nile tilapia (*Oreochromis niloticus* broodstock rearing under unchanged water systems for 84 days

Items	Experimental groups				*P*-value
	CA	CB	Yucca	Biofloc	
Temperature, °C	30.05 ± 0.25[a]	30.00 ± 0.50[a]	30.15 ± 0.45[a]	30.40 ± 0.10[a]	0.864
pH	8.12 ± 0.02[a]	8.15 ± 0.04[a]	7.98 ± 0.03[b]	7.99 ± 0.02[b]	0.020
Dissolved oxygen, mg/L	6.50 ± 0.10[b]	6.95 ± 0.05[a]	6.70 ± 0.10[ab]	6.80 ± 0.10[ab]	0.054
Total ammonia, mg/L	1.59 ± 0.008[a]	0.98 ± 0.012[b]	0.90 ± 0.019[b]	0.88 ± 0.027[c]	0.003
Nitrite, mg/L	0.97 ± 0.002[a]	0.057 ± 0.002[b]	0.055 ± 0.004[b]	0.054 ± 0.004[b]	0.054
Nitrate, mg/L	0.160 ± 0.002[c]	0.169 ± 0.004[bc]	0.178 ± 0.003[b]	0.194 ± 0.003[a]	0.005
T.S.S, mg/L	317.50 ± 7.50[a]	125.50 ± 10.50[c]	305.50 ± 15.50[a]	320.00 ± 5.00[a]	0.001

Means (± SE) in the same row having different superscripts (a, b, c..) differ significantly ($n = 3$, $P \leq 0.05$)

Control A (CA), fish were reared under unchanged water

Control B (CB), water exchange rate of 50% of tank volume weekly

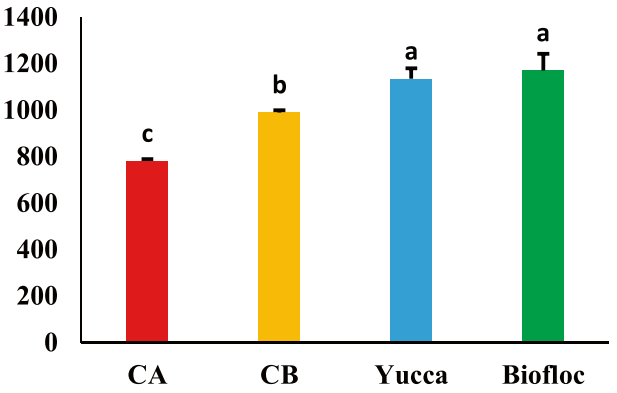


Fig. 1 Absolute fecundity (*P*-value = 0.01) of Nile tilapia *Oreochromis niloticus* broodstock reared under unchanged water systems 20 days after starting the trial. Columns with error bars refer to means ± SE and different superscript letters are different significantly ($n = 3$, $P \leq 0.05$)

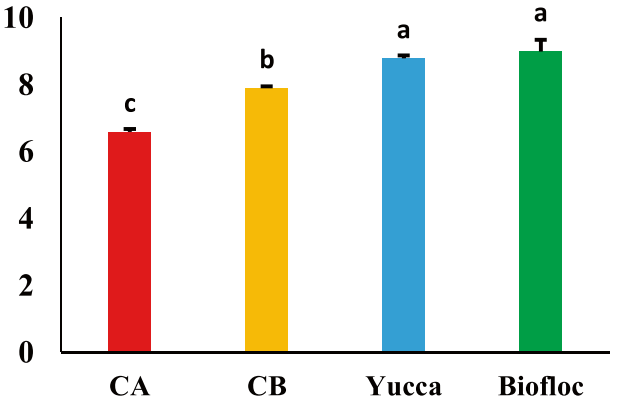


Fig. 2 Relative fecundity (*P*-value = 0.003) of Nile tilapia *Oreochromis niloticus* broodstock reared under unchanged water systems 20 days after starting the trial. Columns with error bars refer to means ± SE and different superscript letters are different significantly ($n = 3$, $P \leq 0.05$)

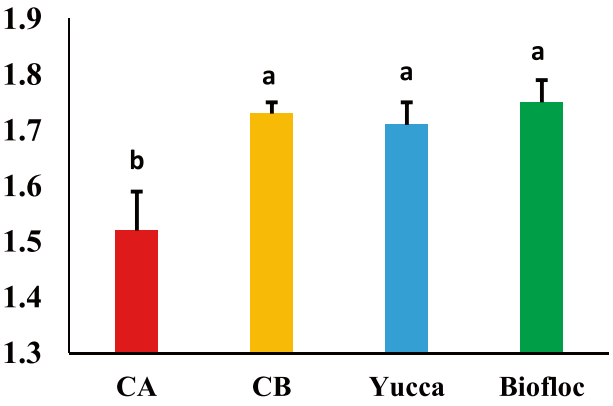


Fig. 3 Egg diameter (*P*-value = 0.051) of Nile tilapia *Oreochromis niloticus* broodstock reared under unchanged water systems 20 days after starting the trial. Columns with error bars refer to means ± SE and different superscript letters are different significantly ($n = 3$, $P \leq 0.05$)

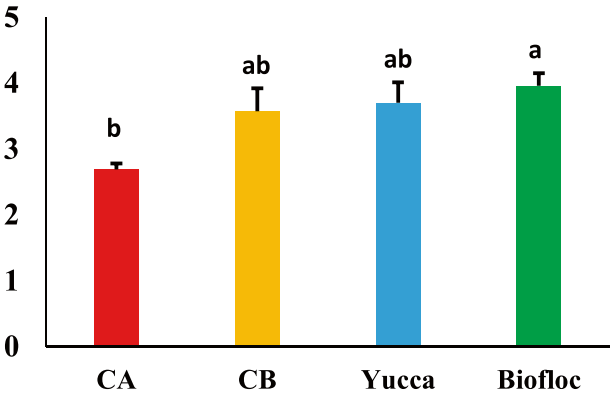


Fig. 4 GSI (*P*-value = 0.054) of Nile tilapia *Oreochromis niloticus* broodstock reared under unchanged water systems 20 days after starting the trial. Columns with error bars refer to means ± SE and different superscript letters are different significantly ($n = 3$, $P \leq 0.05$)

other groups, which did not show statistically significant differences in these parameters. CA also had the lowest dissolved oxygen concentration.

Reproductive performance

Figures 1, 2, 3, and 4 display the reproductive performance indicators 20 days after the trial began. These indicators include absolute fecundity, relative fecundity, egg diameters, and GSI. Significant differences ($P \leq 0.05$) were observed between the groups. The biofloc and yucca groups had the highest values, followed by CB, while CA had the lowest.

Blood sexual hormone levels before spawning

Figures 5, 6, 7, 8, and 9 show the blood sexual hormone concentrations of FSH, LH, estrogen, progesterone, and testosterone 20 days after the trial's start. Statistical analysis revealed significant differences ($P \leq 0.05$) in all hormones among the groups, except for LH in both males and females and FSH and progesterone in males. Biofloc and yucca treatments produced the highest levels of FSH, LH, progesterone, and testosterone in both males and females, followed by CB. In contrast, both female and male CA had the lowest levels of these hormones but recorded the highest levels of estrogen.

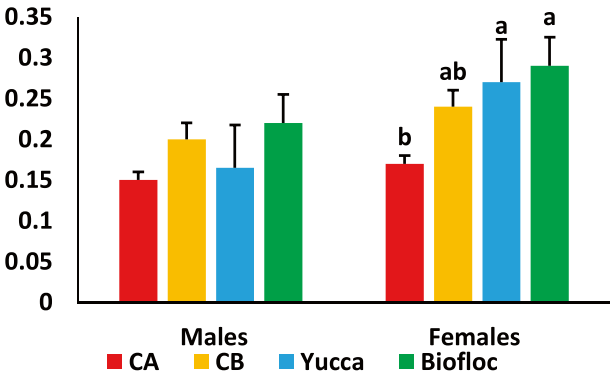


Fig. 5 Concentrations of blood sexual hormones of males and females (FSH of males and female, *P*-value = 0.321 and 0.050) of Nile tilapia *Oreaochromis niloticus* broodstock hatched under unchanged water systems 20 days after starting the trial. Columns with error bars refer to means ± SE and different superscript letters are different significantly ($n = 3$, $P \leq 0.05$)

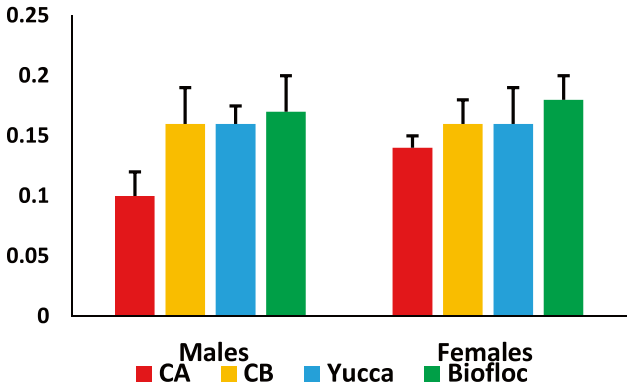


Fig. 6 Concentrations of blood sexual hormones of males and females (LH, *P*-value = 0.184 and 0.452) of Nile tilapia *Oreaochromis niloticus* broodstock hatched under unchanged water systems 20 days after starting the trial. Columns with error bars refer to means ± SE and different superscript letters are different significantly ($n = 3$, $P \leq 0.05$)

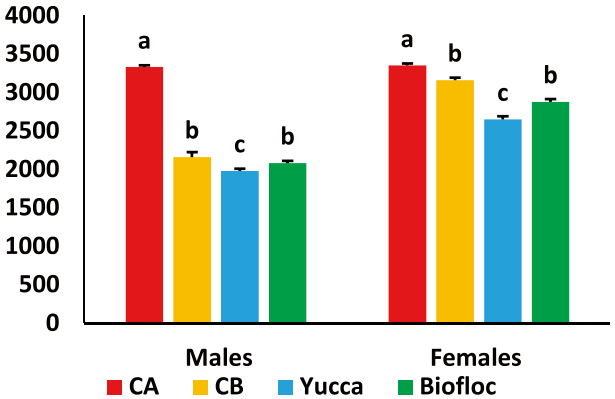


Fig. 7 Concentrations of blood sexual hormones of males and females (estrogen, *P*-value = 0.001 and 0.00) of Nile tilapia *Oreaochromis niloticus* broodstock hatched under unchanged water systems 20 days after starting the trial. Columns with error bars refer to means ± SE and different superscript letters are different significantly ($n = 3$, $P \leq 0.05$)

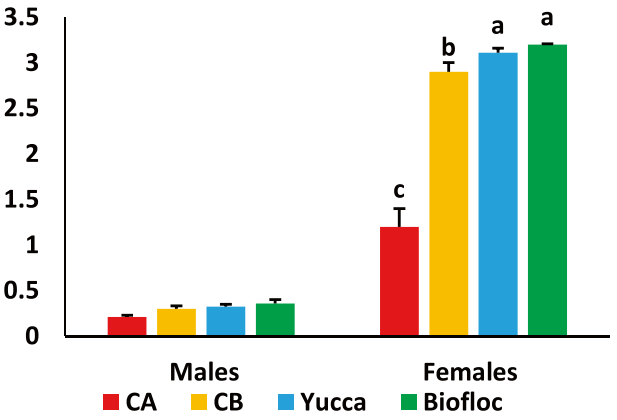


Fig. 8 Concentrations of blood sexual hormones of males and females (progesterone, *P*-value = 0.08 and 0.001) of Nile tilapia *Oreaochromis niloticus* broodstock hatched under unchanged water systems 20 days after starting the trial. Columns with error bars refer to means ± SE and different superscript letters are different significantly ($n = 3$, $P \leq 0.05$)

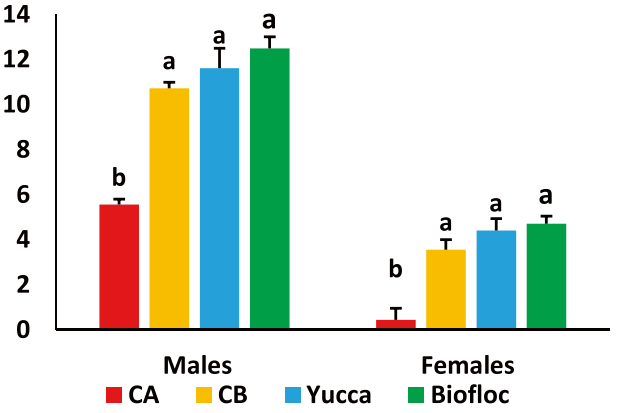


Fig. 9 Concentrations of blood sexual hormones of males and females (testosterone, *P*-value = 0.003 and 0.004) of Nile tilapia *Oreaochromis niloticus* broodstock hatched under unchanged water systems 20 days after starting the trial. Columns with error bars refer to means ± SE and different superscript letters are different significantly ($n = 3$, $P \leq 0.05$)

Table 2 Fry production remarks of Nile tilapia *Oreochromis niloticus* broodstock hatched under unchanged water systems for 84 days

Items	Experimental groups				*P*-value
	CA	CB	Yucca	Biofloc	
First spawning, days	37.00 ± 2.00^{a}	30.50 ± 0.50^{b}	27.50 ± 0.50^{b}	26.00 ± 1.00^{b}	0.009
No. of spawning	2.50 ± 0.50^{b}	3.50 ± 0.50^{ab}	4.00 ± 0.00^{a}	4.00 ± 0.00^{a}	0.054
Fry/tank	1860 ± 420^{b}	4530 ± 210^{a}	5040 ± 240^{a}	5400 ± 300^{a}	0.004
Fry/female	310 ± 70.01^{b}	755 ± 35.01^{a}	840 ± 40.01^{a}	900 ± 50.01^{a}	0.004
Fry/g female	2.60 ± 0.53^{b}	6.02 ± 0.18^{a}	6.51 ± 0.12^{a}	6.91 ± 0.24^{a}	0.002
Fry weight, mg at harvesting	10.60 ± 0.40^{a}	11.05 ± 0.55^{a}	11.30 ± 0.30^{a}	11.60 ± 0.20^{a}	0.414
Fry length, mm at harvesting	9.50 ± 0.50^{a}	10.00 ± 0.00^{a}	10.00 ± 0.00^{a}	10.00 ± 0.00^{a}	0.479

Means (± SE) in the same row having different superscripts (a, b, c..) differ significantly ($n = 3$, $P \leq 0.05$)

Control A (CA), fish were reared under unchanged water

Control B (CB), water exchange rate of 50% of tank volume weekly

Fry production

Table 2 displays significant variations ($P \leq 0.05$) in fry production indicators among groups, except for fry weight and length. Biofloc and yucca groups showed significantly earlier spawning, followed by CB, compared to CA, which spawned 37 days after the experiment started. Similarly, number of spawnings, fry/tank, fry/female, and fry/gram female did not significantly differ in biofloc, yucca, and CB groups; however, these groups showed significantly higher values for these indicators than CA.

Blood measurements

Sexual hormones

Table 3 presents the mean concentrations of blood sexual hormones in males and females during the experimental period. Females in the biofloc, yucca, and CB groups, respectively, had considerably higher levels of FSH, LH, progesterone, and estrogen compared to females in the CA group, which recorded the highest level of estrogen. Following the same trend, sexual hormones in males of biofloc, yucca, and CB groups did not differ significantly throughout the study, and they had significantly higher concentrations than males in the CA group, which recorded the highest levels of testosterone.

Table 3 Concentrations of blood sexual hormones of males and females Nile tilapia *Oreochromis niloticus* reared under unchanged water systems for 84 days

Items	Experimental groups				*P*-value
	CA	CB	Yucca	Biofloc	
Females					
FSHmIU/mL	0.16 ± 0.01^{c}	0.23 ± 0.02^{b}	0.26 ± 0.01^{ab}	0.28 ± 0.01^{a}	0.006
LHmIU/mL	0.13 ± 0.01^{b}	0.15 ± 0.01^{ab}	0.16 ± 0.01^{ab}	0.17 ± 0.01^{a}	0.054
Estrogen, pg/mL	3320 ± 30^{a}	3030 ± 130^{ab}	2540 ± 110^{c}	2765 ± 115^{bc}	0.023
Progesterone, ng/mL	1.08 ± 0.13^{b}	2.86 ± 0.06^{a}	2.98 ± 0.13^{a}	3.07 ± 0.14^{a}	0.0 01
Testosterone, ng/mL	0.48 ± 0.03^{b}	3.35 ± 0.21^{a}	4.17 ± 0.25^{a}	4.34 ± 0.38^{a}	0.001
Males					
FSHmIU/mL	0.14 ± 0.01^{b}	0.19 ± 0.01^{a}	0.20 ± 0.01^{a}	0.21 ± 0.01^{a}	0.026
LHmIU/mL	0.09 ± 0.01^{b}	0.15 ± 0.02^{a}	0.15 ± 0.01^{a}	0.16 ± 0.01^{a}	0.040
Estrogen, pg/mL	3287 ± 37^{a}	2130 ± 30^{b}	1945 ± 35^{c}	$2035 \pm 44b^{c}$	< 0.001
Progesterone, ng/mL	0.19 ± 0.02^{a}	0.27 ± 0.02^{a}	0.28 ± 0.04^{a}	0.31 ± 0.06^{a}	0.302
Testosterone, ng/mL	5.67 ± 0.11^{b}	10.59 ± 0.19^{a}	11.09 ± 0.54^{a}	11.96 ± 0.55^{a}	0.001

Means (± SE) in the same row having different superscripts (a, b, c..) differ significantly ($n = 3$, $P \leq 0.05$)

Control A (CA), fish were reared under unchanged water

Control B (CB), water exchange rate of 50% of tank volume weekly

FSH, follicle-stimulating hormone; *LH*, luteinizing hormone

Table 4 Glucose, liver, and kidney functions of male and female Nile tilapia *Oreochromis niloticus* reared under unchanged water systems for 84 days

Items	Experimental groups				*P*-value
	CA	CB	Yucca	Biofloc	
Females					
Glucose, mg/dL	82.50 ± 2.50^{a}	87.50 ± 2.50^{a}	88.00 ± 5.00^{a}	97.50 ± 7.50^{a}	0.309
ASTU/L	257.50 ± 7.50^{a}	238.50 ± 6.50^{ab}	232.50 ± 2.50^{b}	229.50 ± 1.50^{b}	0.050
ALT, U/L	197.50 ± 7.50^{a}	181.00 ± 9.00^{ab}	152.50 ± 12.50^{b}	116.00 ± 4.00^{c}	0.010
Creatinine, mg/dL	0.72 ± 0.02^{a}	0.62 ± 0.02^{b}	0.59 ± 0.03^{b}	0.57 ± 0.01^{b}	0.017
Urea, mg/dL	8.42 ± 0.09^{a}	6.93 ± 0.22^{b}	6.38 ± 0.14^{b}	4.93 ± 0.09^{c}	< 0.001
Uric acid, mg/dL	3.59 ± 0.04^{a}	2.70 ± 0.08^{b}	2.38 ± 0.03^{c}	2.35 ± 0.03^{c}	< 0.001
Males					
Glucose, mg/dL	115.00 ± 5.00^{a}	127.50 ± 7.50^{a}	127.50 ± 2.50^{a}	132.50 ± 2.50^{a}	0.211
AST, U/L	250.00 ± 5.00^{a}	225.00 ± 5.00^{b}	197.50 ± 7.50^{c}	185.00 ± 5.00^{c}	0.004
ALT, U/L	129.00 ± 4.00^{a}	97.50 ± 7.50^{b}	92.50 ± 7.50^{b}	82.50 ± 7.50^{b}	0.031
Creatinine, mg/dL	0.64 ± 0.02^{a}	0.57 ± 0.02^{b}	0.53 ± 0.02^{bc}	0.51 ± 0.01^{c}	0.008
Urea, mg/dL	6.49 ± 0.08^{a}	5.59 ± 0.14^{b}	5.40 ± 0.07^{bc}	5.18 ± 0.07^{c}	0.002
Uric acid, mg/dL	3.36 ± 0.16^{a}	2.78 ± 0.12^{b}	2.45 ± 0.11b^{c}	2.23 ± 0.04^{c}	0.008

Means (± SE) in the same row having different superscripts (a, b, c..) differ significantly ($n = 3$, $P \leq 0.05$)

Control A (CA), fish were reared under unchanged water

Control B (CB), water exchange rate of 50% of tank volume weekly

AST, aspartate aminotransferase; *ALT*, alanine aminotransferase

Glucose, liver, and kidney functions

Table 4 shows significant variations ($P \leq 0.05$) in liver and kidney function parameters among groups in both females and males, except for serum glucose. Both females and males in the CA group had the highest levels of AST, ALT, creatinine, urea, and uric acid, followed by CB, yucca, and biofloc groups, respectively.

Blood gases

Results of blood gases for both females and males in different treatments are shown in Table 5. All parameters displayed significant differences among groups except pH and HCO_3. The highest values of blood ammonia and pCO_2 were seen in the CA group, followed by CB and yucca, while the biofloc treatment showed the lowest values. Conversely, levels of pO_2 and sO_2 were highest in the broodstock of the biofloc group, followed by yucca and CB. The CA group had the lowest levels of these parameters.

Growth performance of broodstock and fry

The final body weight and weight gain of both male and female broodstock are shown in Table 6. Results revealed that the biofloc, yucca, and CB groups had the highest improvements in weight gain, while the CA group had the lowest weight gain 84 days after the rearing period. Table 7 shows that treatments had a significant impact on fry growth

Table 5 Blood gases of male and female Nile tilapia *Oreochromis niloticus* hatched under unchanged water systems for 84 days

Items	Experimental groups				*P*-value
	CA	CB	Yucca	Biofloc	
Female					
Ammonia, µg/dL	251.88 ± 3.55^{a}	211.18 ± 2.48^{b}	197.59 ± 4.10^{b}	175.08 ± 4.19^{c}	0.001
pH	7.14 ± 0.01^{a}	7.11 ± 0.02^{a}	7.12 ± 0.01^{a}	7.10 ± 0.01^{a}	0.278
pCO_2, mmHg	30.41 ± 0.82^{a}	29.19 ± 0.75^{a}	24.39 ± 0.91^{b}	24.15 ± 1.20^{b}	0.018
pO_2, mmHg	64.22 ± 3.74^{b}	70.14 ± 3.32^{ab}	70.62 ± 4.37^{ab}	78.03 ± 1.56^{a}	0.054
sO_2, %	77.36 ± 1.89^{b}	82.60 ± 0.88^{ab}	87.19 ± 2.37^{a}	87.83 ± 2.49^{a}	0.052
HCO_3 mmol/L	10.74 ± 0.42^{a}	10.07 ± 0.26^{a}	9.98 ± 0.29^{a}	9.88 ± 0.46^{a}	0.433
Male					
Ammonia, µg/dL	278.89 ± 3.09^{a}	241.51 ± 2.49^{b}	237.67 ± 1.11^{b}	225.03 ± 2.99^{c}	< 0.001
pH	7.16 ± 0.01^{a}	7.16 ± 0.02^{a}	7.11 ± 0.01^{a}	7.12 ± 0.01^{a}	0.109
pCO_2, mmHg	27.49 ± 0.97^{a}	26.59 ± 1.23^{a}	25.77 ± 0.66^{a}	23.79 ± 0.90^{a}	0.181
pO_2, mmHg	66.24 ± 3.65^{a}	71.66 ± 3.81^{a}	74.96 ± 2.37^{a}	78.10 ± 1.75^{a}	0.171
sO_2, %	79.33 ± 0.94^{c}	84.40 ± 1.16^{b}	85.34 ± 1.01^{ab}	89.56 ± 1.31^{a}	0.013
HCO_3 mmol/L	11.18 ± 0.61^{a}	10.59 ± 0.24^{a}	10.27 ± 0.12^{a}	10.39 ± 0.09^{a}	0.352

Means (± SE) in the same row having different superscripts (a, b, c..) differ significantly ($n = 3$, $P \leq 0.05$)

Control A (CA), fish were reared under unchanged water

Control B (CB), water exchange rate of 50% of tank volume weekly

Ammonia, NH_3; *pH*, blood pH; pCO_2, partial pressure of carbon dioxide; pO_2, partial pressure of oxygen; sO_2, oxygen saturation; HCO^-_3, concentration of bicarbonate ions

Table 6 Weight gain of male and female Nile tilapia *Oreochromis niloticus* hatched under unchanged water systems for 84 days

Items	Experimental groups				*P*-value
	CA	CB	Yucca	Biofloc	
Females					
Initial weight, g/fish	108.97 ± 2.16^{a}	110.67 ± 1.46^{a}	110.92 ± 3.40^{a}	109.35 ± 2.13^{a}	0.916
Final weight, g/fish	128.28 ± 3.19^{b}	140.06 ± 2.59^{ab}	147.23 ± 4.41^{a}	151.12 ± 3.58^{a}	0.035
Weight gain, g/fish	19.31 ± 1.03^{d}	29.39 ± 1.14^{c}	36.31 ± 1.02^{b}	41.77 ± 1.45^{a}	0.001
Males					
Initial weight, g/fish	141.16 ± 1.65^{a}	138.54 ± 0.72^{a}	140.84 ± 2.46^{a}	140.95 ± 4.08^{a}	0.869
Final weight, g/fish	173.47 ± 4.01^{c}	191.12 ± 3.61^{bc}	204.32 ± 5.04^{ab}	211.91 ± 6.59^{a}	0.019
Weight gain, g/fish	32.32 ± 2.37^{c}	52.59 ± 2.89^{b}	63.49 ± 2.59^{a}	70.96 ± 2.51^{a}	0.002

Means (± SE) in the same row having different superscripts (a, b, c..) differ significantly ($n = 3$, $P \leq 0.05$)

Control A (CA), fish were reared under unchanged water

Control B (CB), water exchange rate of 50% of tank volume weekly

performance. The CA group showed the lowest weight gain, specific growth rate, and highest FCR. In contrast, fry reared under the biofloc system exhibited the bestgrowth performance, survival rate, and FCR, followed by yucca and CB, in that order.

Table 7 Growth performance of Nile tilapia *Oreochromis niloticus* fry cultured under unchanged water systems for 45 days

Items	Experimental groups				*P*-value
	CA	CB	Yucca	Biofloc	
Initial length, cm/fish	0.95 ± 0.05^{a}	1.00 ± 0.00^{a}	1.05 ± 0.05^{a}	1.05 ± 0.05^{a}	0.410
Final length, cm/fish	3.50 ± 0.10^{b}	4.25 ± 0.25^{a}	4.35 ± 0.25^{a}	4.70 ± 0.10^{a}	0.045
Initial weight, g/fish	0.013 ± 0.04^{b}	0.015 ± 0.03^{a}	0.015 ± 0.02^{a}	0.015 ± 0.02^{a}	0.011
Final weight, g/fish	0.78 ± 0.03^{c}	1.28 ± 0.19^{b}	1.57 ± 0.16^{ab}	1.78 ± 0.06^{a}	0.018
Weight gain, g/fish	0.77 ± 0.03^{c}	1.26 ± 0.18^{b}	1.55 ± 0.15^{ab}	1.77 ± 0.06^{a}	0.016
Daily growth, mg/day	17.03 ± 0.61^{c}	28.00 ± 4.00^{b}	34.45 ± 3.34^{ab}	39.22 ± 1.22^{a}	0.016
SGR, %/day	9.11 ± 0.04^{c}	9.87 ± 0.29^{b}	10.32 ± 0.19^{ab}	10.66 ± 0.06^{a}	0.013
FCR, g feed/g gain	1.71 ± 0.020^{a}	1.49 ± 0.015^{b}	1.39 ± 0.015^{c}	1.38 ± 0.020^{c}	0.001
Survival rate, %	68.00 ± 2.00^{b}	87.00 ± 1.00^{a}	90.00 ± 2.00^{a}	91.00 ± 1.00^{a}	0.001

Means (± SE) in the same row having different superscripts (a, b, c..) differ significantly ($n = 3$, $P \leq 0.05$)

Control A (CA), fish were reared under unchanged water

Control B (CB), water exchange rate of 50% of tank volume weekly

Discussion

Water quality is a critical factor in aquaculture, significantly influencing fish physiological activities and overall system effectiveness (Kord et al. 2022). Monitoring and maintaining optimal water quality parameters are essential for sustaining fish growth and survival (Eissa et al. 2022; FAO 2020). Our findings revealed significant variations in pH, dissolved oxygen (DO), and total ammonia among tested groups. While pH and DO remained within acceptable ranges for tilapia reproduction and growth (Ngugi et al. 2007; Makori et al. 2017), elevated total ammonia negatively impacted the performance of AC broodstock compared to biofloc, yucca, and CB groups. This observation aligns with Benli and Köksal (2005), who confirmed that early developmental stages of fish are particularly sensitive to ammonia pollution. El-Greisy and Ahmed (2016) further demonstrated that increased ammonia doses negatively affected fertilized eggs, hatching rates, and egg deformities.

Biofloc and yucca treatments exhibited the lowest ammonia values. Biofloc technology, a sustainable aquaculture method, promotes continuous nutrient recycling and reuse with minimal or no water exchange (Avnimelech 2007; Kuhn et al. 2009). In biofloc systems, fish waste, nitrogenous metabolites, unfed feed, and mucus are converted into microbial biomass, which maintains water quality and serves as a supplementary food source for cultured animals (Debbarma et al. 2022; Mi et al. 2023; Khanjani et al. 2023). Bioflocs consume ammonia to synthesize proteins, thereby maintaining good water quality (Emerenciano et al. 2017; Hassan et al. 2023).

Yucca's ability to reduce ammonia levels has been documented in both freshwater and marine fish (Santacruz-Reyes and Chien 2012; Fayed et al. 2019). Adegbeye et al. (2019) demonstrated that yucca extract has a significant absorption capacity for harmful volatile compounds, such as ammonia. Also, yucca products are mostly used in animal nutrition, where they decrease the odor of animal feces and the amount of ammonia in the environment. Yucca supplementation has been demonstrated having a positive impact on population growth and health (Piacente et al. 2005). These effects are attributed to its content of steroidal saponin fractions, polysaccharides, and polyphenols, which possess surface-active

properties and can bind to ammonia via glycol-component fractions (Cheok et al. 2014). Furthermore, yucca shidigera extract has a significant capacity to bind ammonia, according to Baláži et al. (2013), and Fayed et al. (2019) explained that yucca extract lowered the pH of water, which in turn decreased the concentrations of NH_3. This fact is important for maintaining animal welfare, hence high reproduction performance, whereas increased water pH can reduce sperm motility and survival leading to decreased fertility rates (Amber et al. 2004).

Notably, reproductive indices and blood sexual hormone levels of broodstock reared under biofloc systems or with yucca addition significantly improved compared to those under unchanged water systems or 50% water exchange regimes. These findings corroborate previous studies demonstrating enhanced reproductive performance in various aquatic species under biofloc conditions, including Pacific white shrimp (Braga et al. 2018) and Nile tilapia (Ekasari et al. 2015). Emerenciano et al. (2017) observed increased egg numbers per spawn and decreased latency periods between spawnings in *Farfantepenaeus duorarum* brooders reared in biofloc systems.

The improved reproductive performance can be attributed to the continuous intake of nutrient water–rich biofloc, especially during the pre-spawning phase (Cardona et al. 2016). Biofloc contains a wide range of bioactive compounds, including carotenoids, chlorophylls, phytosterols, bromophenols, amino sugars, vitamins, and minerals (Khanjani et al. 2023 and El-Dakar et al. 2023). This nutrient-rich environment likely contributes to the observed 65% increase in total fry production in biofloc systems compared to clear water systems (Ekasari et al. 2015). The enhanced embryonic development and larval survival observed in biofloc-reared broodstock (Ekasari et al. 2016) may be linked to improved maternal nutrient transfer to offspring. This is particularly relevant given that fish embryonic development is strongly influenced by the broodstock's nutritional status, especially dietary lipids (Kjørsvik et al. 1990; Brooks et al. 1997). Regarding sexual hormones, our results showed that biofloc and yucca groups recorded the highest levels of blood sexual hormones. This observation aligns with Sallam et al. (2024), who illustrated that biofloc increases the availability of energy and essential nutrients, such as cholesterol, the main precursor of steroid hormones. The high levels of highly unsaturated fatty acids (HUFA) (Ekasari et al. 2010) and vitamin C (Crab et al. 2012) in bioflocs likely support gonadal maturation (Dabrowski and Ciereszko 2001).

Besides, evidence that yucca can enhance reproductive processes is mounting. Štochmal'ová et al. (2015) and Balazi et al. (2013) have shown that the spermatozoa parameters of males improved when the *Yucca schidigera* plant was added to the regular diet. Yucca is also a rich source of polyphenolics, including resveratrol and a number of other stilbenes (yuccaols A, B, C, D, and E). These phenolics have anti-inflammatory activity (Cheeke et al. 2006). Due to the lack of studies on the role of dietary yucca on fish reproduction, some works that were conducted on other animals suggested that spermatozoa are very sensitive to inflammation of the testicles. Then, for rabbits that were fed dietary yucca, the quality of rabbit spermatozoa improved than control (Baláži et al. 2013).

Yucca has effects on reproductive hormones profile which are considered to be important regulators of reproduction and fecundity (Földešiová et al. 2017). Yucca action on reproduction might be explained also by its inhibitory action on transcription factor NF-κB which can be involved in the control of proliferation, apoptosis, and steroidogenesis by ovarian cells and which may mediate gonadotropin action on these processes (Pavlova et al., 2013). Also, the addition of yucca increased the rabbit's progesterone secretion (Štochmal'ová et al. 2015). Progesterone may be a potential mediator of yucca stimulatory action on reproductive efficiency because it plays important roles in ovulation, implantation, and the maintenance

of pregnancy, ovarian cell proliferation, apoptosis, luteinization, and folliculogenesis. Additionally, *Yucca schidigera* may be an effective direct natural regulator of ovarian functions, according to Štochmal'ová et al. (2015). In animal production, its stimulatory effect on ovarian function may be helpful in enhancing rabbit and other farm animal reproductive.

The improvements in glucose, AST, and ALT activities observed in the biofloc and yucca groups may be attributed to reduced hemolysis and increased antioxidant power of bioactive compounds in floc and yucca (Mirghaed et al. 2017). The lower levels of urea and creatinine in these groups suggest improved kidney function and gill epithelium integrity (Walker et al., 1990; Shih et al., 2008). The reducing effect of yucca on blood urea has been previously reported in broilers (Balog et al. 1994) that could be mainly due to saponin, stilbenes, and carbohydrates in yucca. These components have been reported to have modulatory effects on renal functions and could increase the clearance of urea and lower blood concentrations of ammonia and urea (Duffy et al. 2001).

Blood gas analysis revealed elevated pO_2 and sO_2 values and decreased blood ammonia, pCO_2, and HCO_3- levels in biofloc and yucca groups. These improvements can be attributed to the active nitrification process in biofloc ponds and yucca's role in reducing ammonia levels through its steroidal saponins and glycol components (Yang and Wang 2015; Piacente et al. 2005). In the same context, the blood physiology of fish and water quality are positively correlated. Higher ammonia in the water environment causes higher blood pH and lower carrying capacity of O_2 (Xu et al. 2021). Accordingly, improvement in reproduction parameters is linked to improvement in blood gas levels, and this is a reflection of the positive effect of biofloc and yucca on water quality. Another study of terrestrial animals by Enaiat et al. (2009) attributed to the increased hatchability and fertility of hens to the ability of yucca to reduce ammonia concentration in the surrounding atmosphere of eggs that could help in adjusting the egg pH brfore laying. Additionally, Cline (1996) showed that administering a commercial additive containing yucca extract to pigs resulted in increased blood oxygen levels and thus improved oxygen supply to the fetuses and decreased rates of death during birth.

The observed improvements in broodstock weight gain and fry growth performance in biofloc and yucca groups can be attributed to the nutritional benefits of biofloc and the positive effects of yucca on water quality and feed efficiency. Biofloc provides essential nutrients and acts as an immunostimulant, enhancing the animal's protection against environmental stress (Rollo et al. 2006; Ekasari et al. 2014). Yucca improves water quality, enhances feed efficiency, and positively affects gut microorganisms, digestive enzymes, and nutrient absorption (Elkhayat et al. 2019; Tabassum et al. 2021).

Conclusion

In conclusion, Nile tilapia broodstock spawned under biofloc systems or unaltered water systems with yucca additions produced higher quality fry and demonstrated improved physiological status and reproductive efficiency. The complementary use of *Y. schidigera* with biofloc technology can enhance growth and immune status of farmed fish through improved water quality parameters. Therefore, it can be said that applying the bioflock system in tilapia hatcheries is one of the practical applications that leads to optimal exploitation of rearing water and improving reproductive efficiency. The use of yucca to maintain water quality is also a practical application, but future studies are needed, especially on the direct effect on sex hormones, which may be more positive in the case of dietary yucca.

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Declarations

Competing interests The authors declare no competing interests.

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