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RESEARCH PAPER

Growth Performance and Proximate Composition of African Catfish (*Clarias gariepinus*) Cultured in Cages and Pens in Northern Benin Water Reservoirs Exposed to Cotton-field Effluents

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Abstract

The potential use of water reservoirs exposed to cotton-fields effluents in northern Benin was explored for African catfish (*Clarias gariepinus*) production. A 120-day experiment was conducted to evaluate the rearing performance of *C. gariepinus* in two culture systems (cage and pen) tested each in two water reservoirs, one located within the cotton basin (Batran) and the other outside (Songhaï). Measured water physico-chemical parameters were within the tolerable limits for *C. gariepinus*. Survival rates were similar among treatments and above 92%. Water reservoir, culture system and their interaction influenced significantly the final mean body weight (g), specific growth rate (%/day), and condition factor (%). The highest values of these parameters were observed in fish from cages at Batran (701.09±38.82 g, 2.88±0.05, and 0.84±0.00), while the same culture system displayed the lowest values (296.83±19.95 g, 2.16±0.06, and 0.67±0.02), statistically similar to those obtained in pens at Songhaï. Feed utilization parameters were similar between the culture systems. Fish with high mean final body weight contained less water and more ash and gross energy ($p<0.05$). We recommend cage culture for improved rearing of African Catfish in northern Benin water reservoirs.

Introduction

The supply of fish to national markets worldwide is achieved through one or the combination of three main ways namely; capture fisheries, aquaculture (fish farming) and importation of fish. West African countries have not done much in promoting and developing fish farming since the past fifty years (Lazard and Legendre, 1994; Lazard, 2009). Indeed, fish production through aquaculture in West Africa was estimated at 373 152 tons in 2016, which accounts for only 0.69% of world farmed fish production of 54 091 148 tons (FAO, 2018a). Freshwater fishes that are mostly used in this region of Africa for farming are the Nile tilapia *Oreochromis niloticus* and African catfish *Clarias gariepinus* (FAO, 2018a).

In Benin, despite the pivotal role in the diet of most people through the supply of protein and micronutrients needs, national fish production of capture fisheries and aquaculture remains low compared to the domestic demand (Rurangwa et al., 2014; MAEP, 2017a; FAO, 2018b). Currently, marine and inland capture fisheries' productions in the country have reached their natural limit (MAEP, 2017a; COMHAFAT, 2014). The only option left for increased domestic production to bridge the gap between supply and demand of fish is through fish farming and aquaculture.

Fortunately, Benin is endowed with abundance of diverse inland water masses such as water reservoirs which are mainly found in the northern part of the country. These water bodies are already widely used for capture fisheries (Pèlèbè et al., 2019a; Azonsi et al., 2008). Fresh inland water bodies are important resources that can be used for aquaculture through cage or pen culture systems (Natarajan et al., 1983; Pèlèbè et al., 2019b). In many countries, the employment of public water reservoirs for fish farming has been growing and is increasingly contributing to the quantities of fish available and accessible to the populations (Thankam et al., 2017; Roriz et al.,2017; Alhassan et al., 2018; Cacho et al., 2020). Benin's government and local authorities have also shown interest in using such fresh water reservoirs of the northern part of the country for fish farming through stocking fish fingerlings directly into open waters (Imorou Toko et al., 2011).

However, a number of constraints are hampering the success of these efforts in the bid to semi-intensify fish farming in the northern Benin water reservoirs (Pèlèbè et al., 2019). Indeed, there is little scientific knowledge (Pèlèbè et al., 2019b; Pèlèbè et al., 2020a) on how best these water reservoirs can support fish growth. Another constraint to fish farming in the northern Benin water reservoirs is the pollution from the large agricultural fields and this pose a huge threat to the survival, growth and quality attributes of farmed fishes (Agbohessi et al., 2015; Sunanda et al., 2016; Clasen et al., 2018; Zoumenou et al., 2019; Zoumenou, 2019; Pèlèbè et al., 2019, Douny et al., 2021; Guedegba et al., 2022). In fact, the northern zone representing about 73% of the country is the main agricultural production area where chemical pesticides are used for crop protection mainly in cotton production (Gouda, 2018). Unfortunately, due to the immense contribution of cotton to the national gross domestic product (GDP), government and decision-makers have not shown much commitment to reducing or curtailing the use of chemical pesticides that are used on the cotton farms. Moreover, actions needed to be undertaken to curtail the use of chemical pesticides and promote the application of less harmful pesticides (bio-pesticides) for the treatment of cotton and other crops in Benin have been largely neglected. Although pesticide residues were obtained in *C. gariepinus* and *O. niloticus*, Zoumenou (2019) reported no health risks associated currently with the consumption of fish caught directly from these water reservoirs.

Pesticides are globally a major concern because some of them have the tendency to persist in aquatic environment and bio-accumulate in organisms (Nowell et al., 2014; Rani et al., 2021; Tudi et al., 2021). Certain pesticides remain in the water column whereas other compounds generally the most harmful ones such as organo-chlorines accumulate in the sediments (Zoumenou, 2019). With these conditions, the effects on the exposed fish depend on its preferable habitat (Agbohessi et al., 2015).

With the knowledge that fish production depends among other factors on the quality of their environment (Boyd and Tucker, 1998), the question of great scientific and applied interest is; which culture system, cage or pen will perform better in terms of rearing performance and nutritional quality of African catfish in water reservoirs located within and outside the cotton basin in northern Benin? Hence, the work reported in this paper was undertaken with hypothesis that cage culture would be more suitable for fish farming than pen culture in northern Benin water reservoirs; especially within the cotton basin. This is because in cages, fish do not have access to aquatic bottom and the sediments.

According to Pèlèbè et al. (2020b), out of 77, levels of the two pesticide residues namely Chlorpyriphos (2.8-12.1 µg/kg) and 4,4'- DDE (1.4- 4.9 µg/kg) quantified in Nile tilapia and African Catfish produced with these two culture systems in the northern Benin are compliant with the international standards of the World Health Organization and the Food and Agriculture Organization. The maximum residue limits in fish are 200 µg/kg (FAO/ WHO, 2016) and 300 µg/kg (FAO/WHO 2009) for DDT and Chlorpyriphos, respectively. Moreover, the human health risk assessment using indicators such as the estimated daily intake and the health risk index revealed no potential adverse health implications in relation to the consumption of these fish (Pèlèbè et al. 2020b).

The aim of the present study therefore, was to assess the growth response, feed and nutrient utilization and carcass composition of *C. gariepinus* reared in cages and pens in water reservoirs located in the northern part of Benin. The essence is to identify the most suitable culture system for improved rearing of the fish species. This will practically support the efforts of local and national authorities to promote aquaculture industry in the numerous water reservoirs of the country. It will also positively impact the private sector aquaculture operators as pertaining to investment options to consider. This study will serve as a scientific baseline for comparable studies in other West African countries with similar aquaculture and agricultural cropping conditions.

Materials and Methods

Study Sites

Two water reservoirs served as experimental sites. These are the Batran (between 11°23'49'' -11°24'1'' North Latitude and 2°21'51'' - 2°22'17'' East Longitude) and Songhaï (between 9°24'1'' - 9°24'34'' North Latitude and 2°41'47''–2°42'25'' East Longitude) water reservoirs. Located at Banikoara in the Benin's cotton basin, Batran water reservoir is an ecosystem of Mekrou River basin. Songhaï water reservoir was formed out of the Okpara River and located outside the cotton basin precisely at N'Dali. Batran water reservoir is located at the cotton production basin while the Songhaï one is outside the cotton production basin. The main agricultural activity around the two reservoirs is market gardening. Figure 1 and Figure 2 show the land use in the immediate catchment areas of Batran and Songhaï water reservoirs, respectively.

Culture Systems and Experimental Design

Fixed cages (1 x 1 x 1.70 m) and cage-enclosures (1 x 1 x 3 m) were used as cages and pens, respectively. Metal frames and nylon nets were used to make the farming units. The set-up of the culture systems was made of a train of three cages and another one of three pens installed in each water reservoir. At the beginning of the experiments, culture systems were installed in order to have 1 m water depth; however, slight variations in the water level were observed on rainy days. The net pockets were adjusted to maintain similar

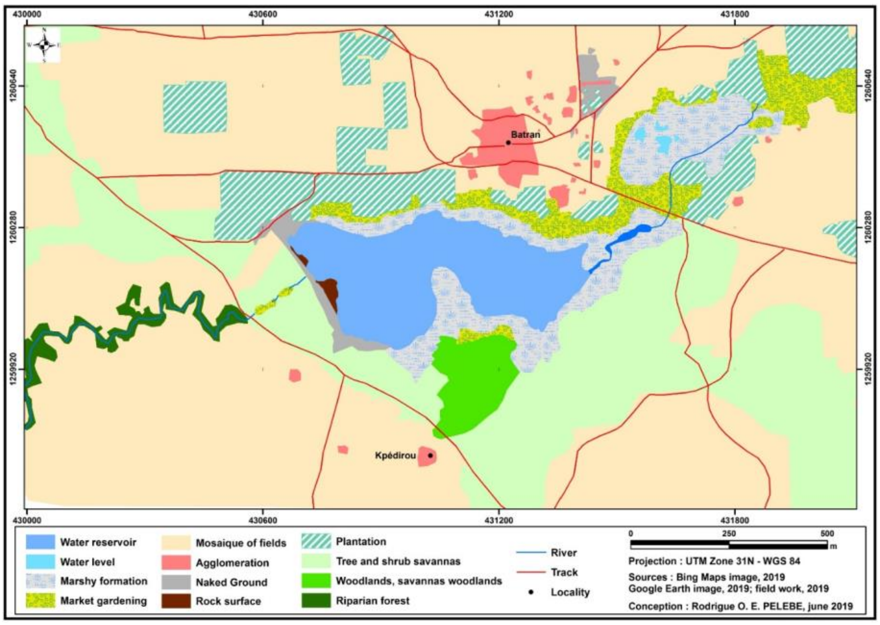

Figure 1. Map of land use in the watershed of the Batran water reservoir

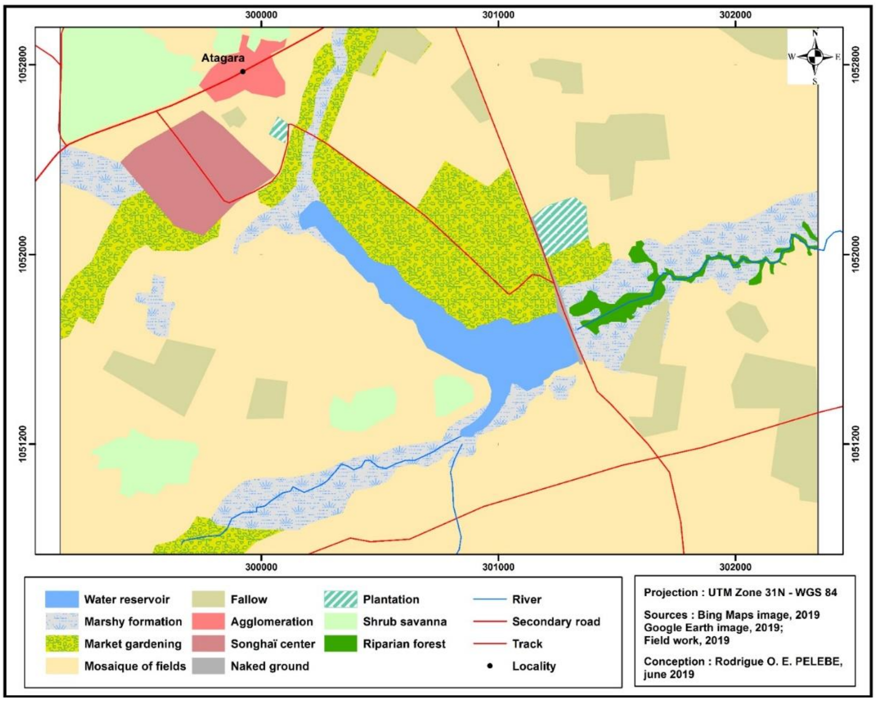

Figure 2. Map of land use in the watershed of the Songhaï water reservoir

water depth in the experimental units. Contrary to the pens which have their bases at the aquatic bottom, the basal nets of the cages were at a distance of 1 m from the aquatic sediment known to be the zone for accumulation of most harmful pesticides. Thus, in cages, the cultured fish had access to only water column, whereas fish in pens had access to both water column and sediments, as in open water.

The experiment had 2 x 2 factorial design based on the two water reservoirs (Batran and Songhaï) and the two culture systems (cages and pens) in triplicates giving a total of three pens and three cages in each reservoir. The culture systems were covered with nets to prevent the fish from jumping out and predation from fish eating birds. In addition, solid fences were installed around the experimental systems to prevent possible damage by animals living in the reservoirs such as crocodiles.

Fish

Healthy African catfish, *C. gariepinus* (homogenous juveniles with average initial weight 22.09±0.2 g) were obtained from a private farm in Abomey-Calavi. Fish were transported to the water reservoirs in the oxygenated plastic bags. Hundred (100) juveniles were randomly stocked per experimental unit. Prior to starting the experiment, the fish were adapted to the culture conditions for two weeks, during which they were fed twice a day with "Le Gouessant" (France) extruded floating commercial pellet feed (3.2 mm).

Trial Procedures and Samples Collection

During the experiment which lasted for 120 days (June-September) in 2017, fish were manually fed twice daily (between 8-9:00 am and 5-6:00 pm) and six days in a week to apparent satiety with "Le Gouessant" fish feeds (42% crude protein and 11% crude lipid) of 3.2 and 5.5 mm diameters. Dead fish were removed and recorded when mortality occured. On 30-days intervals, a sample of 30 fish were netted from each culture unit, their total biomass was recorded using an electronic scale (PHILIPS, 5 Kg and 0.1g), and the daily amount of feeds was readjusted accordingly using the table established by Hecht et al. (1988) for maximum efficiency of the feed. These occasions were also used to check for possible tear and remove waste on the net pockets of the culture systems in order to facilitate free-flow of water through the meshes of the nets.

Water pH, temperature and dissolved oxygen were measured before feeding in each culture unit three days per week at 7:00-8:00 am and 16:00-18:00 pm with an oxy-thermometer (HANNA HI 9146) and pH meter (WTW 3210). Secchi disc transparency was also monitored at the same time during the experiment.

At the end of the experiment, all fish in each culture unit were netted and counted. Ten (10) fish from each culture unit (replicate) were anesthetized using tricaine methane sulfonate (MS-222, 400 mg/l, Sigma-Aldrich, Brussels, Belgium) and measured individually for weight and total length, giving a total of 30 individuals for each culture system. Furthermore, three anesthetized fish were randomly selected from each culture unit, sacrificed and pooled in one sample to determine proximate composition.

Proximate Biochemical Analysis

Analyses of fish proximate composition were made at the Nutrition Laboratory of the Oceanology Research Centre in Abidjan according to AOAC (2003). Dorsal muscle samples were oven-dried at 105°C during 24 hr to calculate moisture. Crude protein, crude lipid and total ash were determined using the Kjeldahl method (N × 6.25), Soxhlet extraction with petroleum ether (40-60 °C) and incineration at 550°C for 12 hr, respectively. Triplicate determinations were carried out on each chemical analysis. Carbohydrates were computed by subtracting the sum of the values for crude protein, crude lipid, moisture and ash from 100 (Jobling, 1983).

Calculations

Survival, growth response and feed utilization parameters were determined using formulas given in Table 1.

Table 1. Calculated parameters to assess the rearing performance

Parameters	Formulas
Survival and growth parameters	
Survival rate SR (%)	100 × (final fish number) / (initial fish number)
Final mean body weight W_f(g)	$B_f N^{-1}$ where B_f = final fish biomass (g) and N = number of survivors
Variation coefficient of final mean body weight CV_f (%)	100 (SD mean^{-1}) where SD = standard deviation
Daily weight gain DWG (g/day)	$(W_f - W_i)\ t^{-1}$ where W_i = initial mean body weight (g) and t = duration of experiment (days)
Specific growth rate SGR (%/day)	$100 \times [\ln(W_f) - \ln(W_i)]\ t^{-1}$
Condition factor K (%)	$100\ W_f\ LT^{-3}$ where W_f is in g and LT= fish total length (cm)
Feed utilization parameters	
Feed efficiency FE	$(B_f - B_i)$ (weight of total feed used) $^{-1}$
Protein efficiency ratio PER	$(B_f - B_i)$ / weight of total used proteins
Gross energy kJ/g (Jobling, 1983; 1994)	(% crude protein x 23.7) + (% crude lipid x 39.5) + (% Carbohydrates x 17.2)

Statistical Analysis

Results are presented as means ± standard deviation of the mean. All the statistical analyses were performed using Statistica 6.1 software (Statsoft, Inc.). Zootechnical data and data on biochemical composition of fish were subjected to two-way analysis of variance (two-way ANOVA) to evaluate effects of water reservoirs and culture systems as factors. When overall differences were found, multiple mean comparisons were done using post hoc Tukey's test. The differences observed were defined as statistically significant at the 5% level (*p*).

Results

At the Batran water reservoir, the pH measures were 6.81±0.59 and 6.93±0.35, the dissolved oxygen 3.18±1.43 and 3.13±1.36 mg/l, the temperature 28.45±2.22 and 28.72±2.08°C, and Secchi disc transparency 18.79 and 19.13 cm, respectively in pens and cages. At the Songhaï reservoir, the values of pH, dissolved oxygen, temperature and Secchi disc transparency were 6.69±0.36 and 6.54±0.57, 4.73±0.91 and 5.04±1.03 mg/l, 28.25±1.4 and 28.08±3.56°C, 31.25 and 34.69 cm in pens and cages respectively

Fish survival ranged from 92.67 (pens at Batran) to 99% (for both pens and cages at Songhaï); the value obtained with caged fish at Batran was 98.67%. There was no significant difference between culture systems and water reservoirs for this parameter ($p>0.05$). Fish growth curve during the experiment is presented in Figure 3. Regardless of the water reservoir and culture system, the growth pattern showed that fish mean body weight increased along the experiment (Figure 3).

The effects of water reservoir, culture system and their interaction on the fish growth performance are presented in Table 2. At the end of the trial, the highest heterogeneity in fish weight was observed from Songhaï pens. The highest values of the final mean body weight (W_f,), daily weight gain (DWG), specific growth rate (SGR) and condition factor (K) were observed from cage culture system at Batran and the lowest values were recorded with the same culture system in the Songhaï water reservoir. The two main tested factors and their interaction had significant effect on W_f and DWG; water reservoir factor did not significantly influence SGR. Differences were significant between pens and cages in Batran, between Batran cages and Songhaï cages, between Songhaï cages and Batran pens and between Songhaï pens and Batran cages. Only water reservoir and its interaction with culture system had a significant

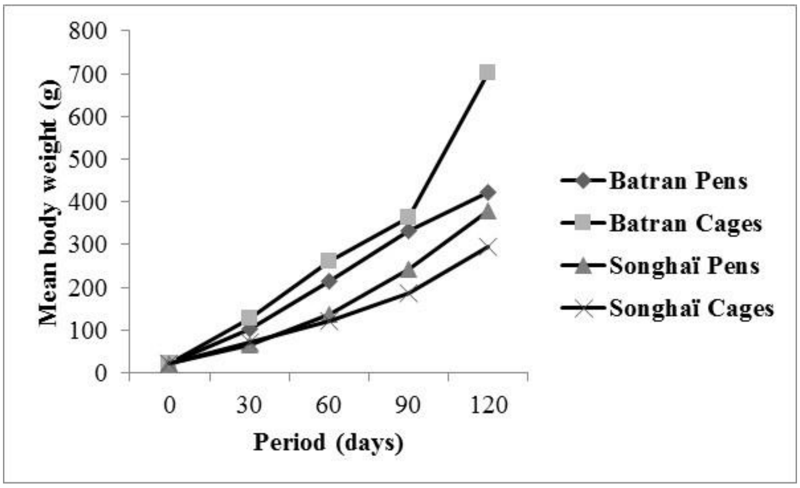

Figure 3. Changes in the *C. gariepinus'* mean body weight during the 120 days rearing period in the northern Benin water reservoirs

Table 2. Growth performance of African catfish (*C. gariepinus*) reared in two culture systems in Batran and Songhaï water reservoirs for 120 days (n=3)

Water reservoir	Culture system	W_i (g)	W_f (g)	CV_f (%)	DWG (g/day)	SGR (%/day)	K (%)
Batran	Pens	21.91±0.08 ^{a}	421.97±10.55 ^{a}	2.5	3.33±0.09 ^{a}	2.46±0.09 ^{a}	0.75±0.04 ^{adb}
	Cages	22.01±0.12 ^{a}	701.09±38.82 ^{d}	5.54	5.66±0.32 ^{d}	2.88±0.05 ^{d}	0.84±0.00 ^{d}
Songhaï	Pens	22.35±0.54 ^{a}	378.67±75.40 ^{abc}	19.91	2.97±0.63 ^{abc}	2.35±0.19 ^{abc}	0.73±0.04 ^{abc}
	Cages	22.07±0.06 ^{a}	296.83±19.95^{bc}	6.72	2.29±0.17 ^{bc}	2.16±0.06 ^{bc}	0.67±0.02 ^{bc}
Observed effect after two-way ANOVA							
Water reservoir		ns	s	-	s	s	s
Culture system		ns	s	-	s	ns	ns
Water reservoir x Culture system		ns	s	-	s	s	s

effect on K. It significantly varied between the Songhaï pens and Batran cages on one hand and between the two water reservoirs for the cages on the other hand. It was noticed that all calculated growth parameters were statistically similar between the two culture systems in the Songhaï water reservoir.

Feed utilization parameters are shown in Table 3. Mean values of FE and PER were similar between the culture systems for the two water reservoirs ($p>0.05$). The results of fish body composition are shown in the Table 4. Water reservoir or its interaction with culture system had significant effect on the moisture content and total ash. There was significant difference in the moisture content between the two water reservoirs for cages and between the two culture systems in Batran water reservoir. Total ash values were significantly different between Songhaï pens and the two culture systems in Batran water reservoir. It is important to note that there was no difference between the two rearing systems for these two parameters, regardless of the water reservoir, except for moisture content at Batran. Lipid, protein and carbohydrate levels were not varied significantly considering the culture systems and water reservoirs. However, there was a significant difference between gross energy content in fish between Batran and Songhaï for cages (Figure 4A). Protein had the highest percentage of contribution to the gross energy formation while, carbohydrate had contributed very little (Figure 4B). In addition, in the two water reservoirs, the contribution of carbohydrate to gross energy content in pens was significantly lower as compared to the cages.

Discussion

Fish culture in cages and pens are two well-known practices in open water bodies in Asia and many African countries, however, the practice started in Benin in recent years (Edea et al., 2018 a; Aïzonou et al., 2019; Pèlèbè, 2019). In the present study, we tested for the first time the performance of cages and pens in the rearing of *C. gariepinus* in two water reservoirs in northern Benin. Fish cultures were conducted simultaneously in Batran and Songhaï water reservoirs located within and outside the cotton basin, respectively. Overall, all the measured water quality parameters (pH, dissolved oxygen, temperature and water transparency) in the two reservoirs were within the acceptable range for rearing *C. gariepinus* as earlier noted (Viveen et al., 1985; Degani et al., 1988; Uzoka et al., 2015).

After 120 days of rearing, the overall fish survival rates in cages and pens were high (between 92.67 and 99%), this is an indication that the culture system was not a limiting factor for *C. gariepinus* survival in the experimental water reservoirs. These survival percentages are comparable to those reported by Dasuki et al. (2012) (99.5-99.84%) and Umaru et al.

Table 3. Feed and nutrient utilization parameters of African catfish (*C. gariepinus*) reared in two culture systems in Batran and Songhaï water reservoirs for 120 days (n = 3)

Water reservoir	Culture system	FE	PER
Batran	Pens	1.97±1,28 [a]	4.7±3.06 [a]
	Cages	2.99±1.32 [a]	7.12±3.14 [a]
Songhaï	Pens	2.17±0.6 [a]	5,17±0.61 [a]
	Cages	2.48±0.82 [a]	5.9±1.95 [a]
Observed effect after two-way ANOVA			
Water reservoir		ns	ns
Culture system		ns	ns
Water reservoir x Culture system		ns	ns

Data are presented as means ± standard deviation. In each column, means followed by at least one letter in common are not significantly different (p>.05). FE, feed efficiency; PER, protein efficiency ratio; ns, non-significant effect

Table 4. Proximate biochemical composition (% of fresh muscle matter basis) of African catfish (*C. gariepinus*) reared in two culture systems in Batran and Songhaï water reservoirs for 120 days (n=3)

Water reservoir	Culture system	Moisture	Total ash	Crude lipid	Crude protein	Carbohydrate
Batran	Pens	77.32±3.50[bc]	0.56±0.09[bc]	5.38±1.00[a]	16.35±2.37[a]	0.38±0.13[a]
	Cages	72.00±0.43 [a]	0.70±0.01[bc]	8.73±0.27[a]	16.54±0.82[a]	1.40±1.28[a]
Songhaï	Pens	75.19±0.19[ac]	0.90±0.06 [ad]	4.28±0.45[a]	19.38±0.19[a]	0.25±0.12[a]
	Cages	78.71±2.67[bc]	0.74±0.09[cd]	3.39±0.35[a]	16.58±2.23[a]	0.58±0.15[a]
Observed effect after two-way ANOVA						
Water reservoir		ns	s	ns	ns	ns
Culture system		ns	ns	ns	ns	ns
Water reservoir x Culture system		s	s	ns	ns	ns

Data are presented as means ± standard deviation. In each column, means followed by at least one letter in common are not significantly different (p>.05); ns, non-significant effect; s, significant effect

(2016) (87-99%)) in *C. gariepinus* reared in cages. They are however above the 72% reported by (Coulibaly et al., 2007) in cage culture of Vundu catfish (*Heterobranchus longifilis*) at man-made Lake Ayame in Côte d'Ivoire. A higher heterogeneity of final fish weight in pens may result from differences in feed intake by individuals (Umino et al., 1997) due to social hierarchy. However, values of coefficient of variation were in the range observed in most fish species (25-35%) as reported by Gjedrem (1997). There were significant differences of growth parameters such as final mean body weight (W_f), daily weight gain (DWG) and specific growth rate (SGR) between culture systems and water reservoirs. Compared to Songhaï, fish reared at Batran water reservoir exhibited better growth response. This is an unexpected result considering our hypothesis, as the Batran water reservoir was reported to be more polluted with pesticide residues than that of Songhaï (Zoumenou, 2019; Guedegba, 2019). Indeed, Sabra and Mehana (2015) noted an adverse effect of some pesticide molecules, known as the most harmful component of agricultural effluents (Tudi et al., 2021), on fish somatic growth. In this study, there were no significant differences between the feed utilization parameters, regardless of water reservoir and culture system. Such an outcome reflects the fact that fish have grown proportionally with the amount of feed consumed. This could justify the sudden gain of weight observed with fish in cages at Batran in the last month of the experiments, corresponding to the period where the amount of the feed distributed to those caged fish at Batran was the highest as compared to all the installed experimental culture systems. Nevertheless, it is also important to note that agricultural effluents contaminating Batran water reservoir are composed of a complex mixture of pesticides. According to Celander

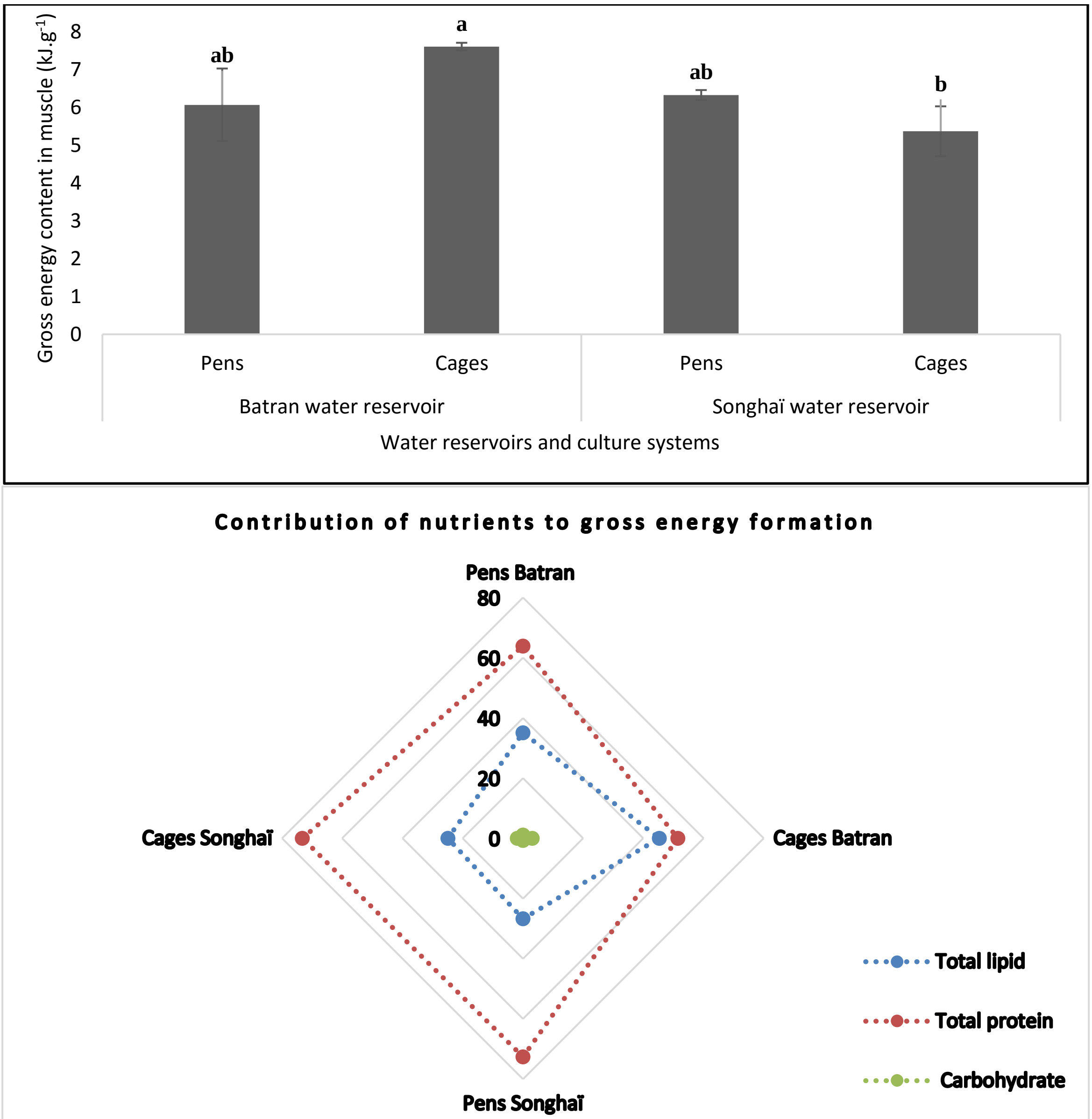

Figure 4. (A) Gross energy content in muscle of African catfish (*C. gariepinus*) reared in two culture systems in Batran and Songhaï water reservoirs for 120 days (n=3); (B) percentage of contribution of nutrient components to gross energy formation in reared *C. gariepinus*

et al. (2011), pollutant cocktails have multiple biological effects that are difficult to understand and predict. Often, exposure to a mixture of pollutants may cause effects different from those induced by the individual pesticide compounds that make up that mixture (Celander, 2011). Future studies may be needed to investigate levels of growth hormone and insulin-like growth factors, which are involved in fish growth process, in water and fish from northern Benin reservoirs. Growth hormone and insulin-like growth factor 1 (IGF-1) have been reported to modulate many growth-related processes in the fish body including skeletal and soft tissue growth and nutrient (lipid, protein, and carbohydrate) metabolism (Reinecke et al., 2005; Ndandala et al., 2022). The superior growth of fish reared in Batran could be due to increased levels of these hormones at the sub-individual level as a positive correlation has been reported between these endocrine biomarkers of growth and cell proliferation as well as the fish specific growth rate (Picha et al., 2008).

The obtained final mean body weight in cage culture system at Batran water reservoir is higher than 693 g recorded in *C. gariepinus* (initial weight of 6.3 g and stocking density of 75 individuals/m^3) by Dasuki et al. (2012) during a 150-day experiment in floating cages placed in Kubanni water reservoir, Nigeria. Also, the weight reached by fish farmed in Batran pens is better than 364.93 g registered by Hengsawat et al. (1997) in *C. gariepinus* (34.42 g initial weight) reared in cages during 8 weeks at 100 fish/m^3. In the same line, fish farmed in both culture systems at Songhaï water reservoir had grown bigger than *C. gariepinus* cultured in cages during 10 weeks (from 5.9-6.6g to 53.3-88.2 g) (Bureau et al., 1995) and *Heterobranchus longifilis* (from 13.1g to 105 g) reared for 270 days in cages at the man-made Lake Ayame (Coulibaly et al., 2007). The daily weight gain and the specific growth rate are inferior compared to 7.61 g/day and 3.43%/day respectively from Edea et al. (2018a) and Dasuki et al. (2012).

In general, feed utilization namely feed efficiency (FE) and protein efficiency ratio (PER) in our study were higher than those found in Dasuki et al. (2012) (FE of 0.3) and Edea et al. (2018 a) (FE of 0.83 and PER 1.85). This good performance in feed and nutrient utilization indicated that the fishes had extracted efficiently nutrient from the feed and converted it into flesh. The difference between fish in terms of moisture and ash was probably the consequence of the difference between the final weights obtained since fish with high final mean body contained less water and more ash. This is comparable to the findings of Edea et al. (2018 b) on *C. gariepinus*. The fact that the ash contents overall were very low indicated that the assays were carried out in the muscle of the fish without bone deemed very rich in minerals that form ash. Although the differences between culture systems and water reservoirs had not reached statistically significant level in terms of lipid, protein and carbohydrate, some important remarks remain to be discussed. Indeed, the highest lipid values and the lowest protein values were obtained at Batran, the most contaminated site by cotton-fields effluents. This could be explained by the fact that apart from lipid derived from feed, in stressed conditions, fish use lipogenesis phenomena to transform substrates primarily from amino acids catabolism to fatty acids (Henderson and Tocher, 1987), representing lipid which fish stored in tissues as triglycerides reserves (Sheridan, 1988; Sheridan, 1994). These neutral lipids are used as alternative sources of energy in the form of ATP through the ß oxidation (Froyland et al., 2000). As for carbohydrate, the lowest values were obtained in pens which exposed fish more, regardless of the water reservoir. This may be an indication that muscle carbohydrate content was used as the principal and immediate energy source to cope with the existing stress in pen environment. Thus, carbohydrate depletion is due to the increase of glycogenolysis induced by an elevation of the activities of phosphorylase, succinate and pyruvate dehydrogenase leading to anaerobic metabolism during anoxic stress conditions caused by chemical pollutants (Kharat et al., 2009). Water reservoir and their interaction with culture system had a significant effect on fish energy content. There was a significant difference in gross energy content of fish reared in Batran cages and Songhaï cages where the highest and the lowest final mean body weights respectively were observed. This finding is in relation to the variation of nutrient contents with the fish weight since energy is derived from nutrient metabolism. In addition, protein was nutrient that contributed more to gross energy content. This result is in agreement with the knowledge that protein is a prominent source of energy in fish (Jobling, 1994).

Moreover, the consumption by both adults and children of those fish we investigated on their zootechnical performance in the current study does not have health implication risks with their content levels of pesticide residues according to Pèlèbè et al. (2020b). Considering these results, it is advisable to rear *C. gariepinus* in cages in the northern Benin water reservoirs. This study provides basic information useful for the development of a healthy production chain of *C. gariepinus* in the Benin water reservoirs.

Conclusions

The present study demonstrated the technical possibility of utilizing two northern Benin water reservoirs for cage and pen farming of *C. gariepinus*. It revealed that fish reared in cages performed better than those cultured in pens at the Batran water reservoir. There was also no significant difference between performance of *C. gariepinus* in cages and pens at Songhaï. Therefore, cage culture could be used for the development of fish farming in water reservoirs located at the cotton basin and both culture systems outside the cotton basin. But, taking into account the practical advantages of cages and the fact that *C. gariepinus* is a benthic fish, we recommend its culture in cages outside the cotton basin also to avoid its contact with sediments. However, in order to prevent health risks, the monitoring of food chains in the Benin cotton basin should be considered since at household level, fish are consumed with other commodities that are also produced in areas exposed to pesticide residues.

Ethical Statement

There is currently no official committee at the level of the University of Parakou that issues ethical documents on animals with code systems. However, the research protocols for the experiments were approved by the Department of Science and Techniques of Animal and Fisheries Productions, Faculty of Agronomy, University of Parakou, Benin. The experiments were conducted under control and following the guidelines for the care and use of animals, especially the code of practice for the housing and care of animals and the guidelines of the European Animal Research Association.

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Author Contribution

R.O.E.P.: Design of the research protocol, Funding acquisition, Experiment implementation, Nutrient analyses, Data processing and statistical analysis, writing of the original draft, Manuscript correction. I.N.O.: Funding acquisition, Supervision of laboratory work, Revision of the paper, Validation of the final draft of the manuscript. P.T.A.: Supervision of field experiment, Revision of the paper, Validation of the final draft of the manuscript. E.Y.A.: Supervision of the field experiment, Revision of the paper, Validation of the final draft of the manuscript. P.A.D.M.: Revision of the paper, Validation of the final draft of the manuscript. E.E.: Revision of the paper, Validation of the final draft of the manuscript. J.F.: Revision of the paper, Validation of the final draft of the manuscript. D.W.A.: Revision of the paper, Validation of the final draft of the manuscript. B.E.: Revision of the paper, Validation of the final draft of the manuscript. I.I.T.: Validation of the research protocol, Funding acquisition, Supervision of field experiment, Revision of the paper, Validation of the final draft of the manuscript. E.M.: Supervision of the field experiment, Revision of the paper, Validation of the final draft of the manuscript. C.M.B.: Supervision of laboratory work, Revision of the paper, Validation of the final draft of the manuscript.

Conflict of Interest

Authors declare that there is no conflict of interest.

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