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Effect of Aquaculture Conditions on the African Catfish *Clarias Gariepinus* Growth Performance, Hematological, Biochemical, and Histological Parameters

Mahmoud M. El-Mezayen[1*], Zeinab S. Farag[2], Hamada A. Areda[3]
[1]National Institute of Oceanography and Fisheries, Egypt
[2]Food Science Dep., Faculty of Agriculture, Damietta University, Egypt
[3]Animal Poultry and Fish Production Dep., Faculty of Agriculture, Damietta University, Egypt
[*]**Corresponding Author: m.elmezayen@gmail.com**

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ABSTRACT
The African catfish is one of the most promising candidates in freshwater aquaculture. Despite the rapid expansion of the catfish farming, it has been facing several limitations regarding feeding and water quality. This study evaluated the effect of two different aquaculture conditions on the African catfish (*Clarias gariepinus*) growth performance, hematological, biochemical, and histological parameters. Replicate water and fish samples were collected from the earthen ponds of the two common types of aquaculture practices at two farms in Egypt in July 2022. The first farm represents the good condition of poly-culture of catfish with other species, fed proper manufactured diet, and reared in a good water environment. The second farm represents the bad conditions of water, where only catfish are cultured and fed poultry by-product meals without any treatment. All data were clustered into two groups and were statistically subjected to paired comparison (t-test) analysis. The response of catfish to the studied aquaculture condition was significantly affected, in terms of body composition (water and lipid), growth performance, survival rate, hematological parameters, and histopathology of catfish, where most of these parameters were enhanced under good aquaculture conditions ($P \leq 0.05$). However, unexpected enhanced weight gain and muscle protein of catfish were observed in bad aquaculture conditions. We conclude that aquaculture conditions, including water and feeding practices, produce complex effects on the general physiology, quality, and quantity of catfish, which may be related to the biological habits of catfish.

INTRODUCTION

The food security issues have attracted the enhanced attention of investigators throughout the globe. The improvement of the aquaculture sector is considered a challenge to enhancing global food security, especially as capture fisheries yields decline, particularly during the COVID-19 pandemic in 2020 **(FAO, 2023)**. Fish are used as an important bio-indicator of aquatic environmental pollution due to direct contact with the surrounding environment, which reflects measurable changes in the biology and physiology of the exposed fishes **(Javed & Usmani, 2017; Plessl *et al.*, 2017; Ali *et al.*, 2020)**. They are abundant in a wide geographical range worldwide, relatively easy to sample, and frequently show predictable associations between contaminant levels in their tissues and various morphological and histological traits **(Van der Oost *et al.*, 2003)**. Therefore, fish have been used to monitor the levels of exposure to contaminants.

The African catfish (*Clarias gariepinus*) is an economical protein source for low-income people worldwide. The catfish is one of the most tolerant species to severe aquaculture environmental conditions **(Okechi, 2004; Oluah & Mgbenka, 2020)**. However, it cannot withstand the low water temperature **(Peteri *et al.*, 1992)**. They are characterized by their ability to thrive in a wide range of aquatic environments, from healthy to highly deteriorated waters. In addition, they have high yield potential and growth rates, even under high stocking densities, are disease-resistant, very tasty, and have a low cost of rearing **(Chor *et al.*, 2013; Bake *et al.*, 2016; Romanova *et al.*, 2018; Adéyèmi *et al.*, 2023)**. Therefore, it is one of the most commonly cultivated freshwater fish worldwide **(FAO, 2024a)**.

Global aquatic animal production grew to reach 185.4×10^6 metric tons (MT) in 2022, from which aquaculture accounted for 59% (130.9×10^6 MT), which was the first time in history that aquaculture production exceeds the production from fisheries **(FAO, 2024b)**. While in Egypt, fish production was reported at 2.0×10^6 MT in 2022 **(FAO, 2024b)**. Aquaculture comprised over 77.5% of the total Egyptian fish production with 1.55×10^6 MT in 2022 **(GAFRD, 2024)**.

Global production of the catfish reached 6.5×10^6 MT in 2022, from which 1.3×10^6 MT is coming from the aquaculture sector, exhibiting 15-fold increase than that produced from the catfish culture in 2010 **(FAO, 2024b)**. This remarkable increase helped the catfish to rank 2nd globally after carp during 2022, after it was 3rd next to cichlids during 2021 **(FAO, 2024b)**.

Egypt is the third largest producer country of the catfish worldwide by sharing approximately 8.47×10^3 MT of the catfish from aquaculture in 2021 **(FAO, 2023)**. Despite the significant rapid expansion, the aquaculture industry in Egypt still faces major challenges and constraints. One of the major limitations facing aquaculture is to provide appropriate feeding, in terms of cost, quantity, and constituents. The success of aquaculture depends on the balanced achievement between these feeding factors, especially when the feeding needs of the cultured species are considerably high. Although the African catfish is considered a good candidate in aquaculture, the farmers could hardly achieve this balance, as the feeding costs represent 80% of the production costs of the catfish **(Ali *et al.*, 2024)**. Therefore, the farmers of the catfish may conduct bad aquaculture feeding practices to achieve more economic profit regardless of the quality of the produced fish **(El-Shebly, 2006; Obe & Omodara, 2014)**.

In this case, inappropriate feeding may cause a remarkable deterioration of water quality, decrease feed utilization, and increase susceptibility to disease infection **(Priestley *et al.*, 2006)**. Several tissues and organs and their enzymes, physiological functions, and ability to resist diseases are also affected as a consequence of aquatic pollution **(Reddy & Rawat, 2013)**. Various sensitive biochemical parameters in fish could be used to identify potential adverse effects of pollutants (**Al-Asgah *et al.*, 2015**). The morphological and biometric parameters are not usually able to give a complete picture of fish health condition without hematological and histopathological examination **(Fazio, 2019)**.

Despite the rapid expansion of the catfish aquaculture in Egypt and globally, there are restrictions on exporting these cultured fish due to the inability to meet food safety criteria. Additionally, studies on the aquaculture conditions of African catfish are limited. Therefore, this study aimed to evaluate the effect of two different aquaculture practices on the growth performance, hematological, biochemical, and histological parameters of the African catfish (*C. gariepinus*).

MATERIALS AND METHODS

1. Study area

Lake Manzala is the largest lake of the northern lakes in terms of surface area. It is located eastward of the Nile Delta between 31º 16` N and 32º 12` E, where Port Said Governorate is located east of the lake, and Damietta is located to the west (Fig. 1). The surface area of the lake has been subjected to shrinkage throughout the last decade from 700 to 288km^2, according to **El-Shazly *et al.* (2017)**. This shrinkage may be due to siltation, urbanization and land reclamation, heavy pollution loads, and fish farming within the lake **(El-Mezayen *et al.*, 2018)**. Fish aquaculture areas of approximately 150km^2 of earthen ponds are located within the main lake **(Toews, 1986)**.

The southern limit of the lake is now defined by the El-Salam canal, which brings the Nile water to the eastern deserts of north Sinai, separating the fish farming facilities from Lake Manzala. The canal was planned to provide water for the cultivation of 150,000 hectares in north Sinai out of the total targeted 248,000 hectares **(Othman *et al.*, 2012)**. Down to the canal and southwest of the lake, many freshwater fish ponds were raised for aquaculture by traditional means. Few fish farms applied the new technology practices. A large number of these aquaculture facilities have been practicing the catfish farming for several years.

1.1. Sampling sites

Sampling was carried out from both types of aquaculture practices during July 2022. The first farm (Elserw Fish Research Station, which belongs to the National Institute of Oceanography and Fisheries) represents the new technology poly-culture of fish, which is farming the catfish with tilapia, carp, and mullets, while the second farm (Elsalam farm) represents the traditional fish farms which conduct monoculture of fish, farming only the catfish (Fig. 2).

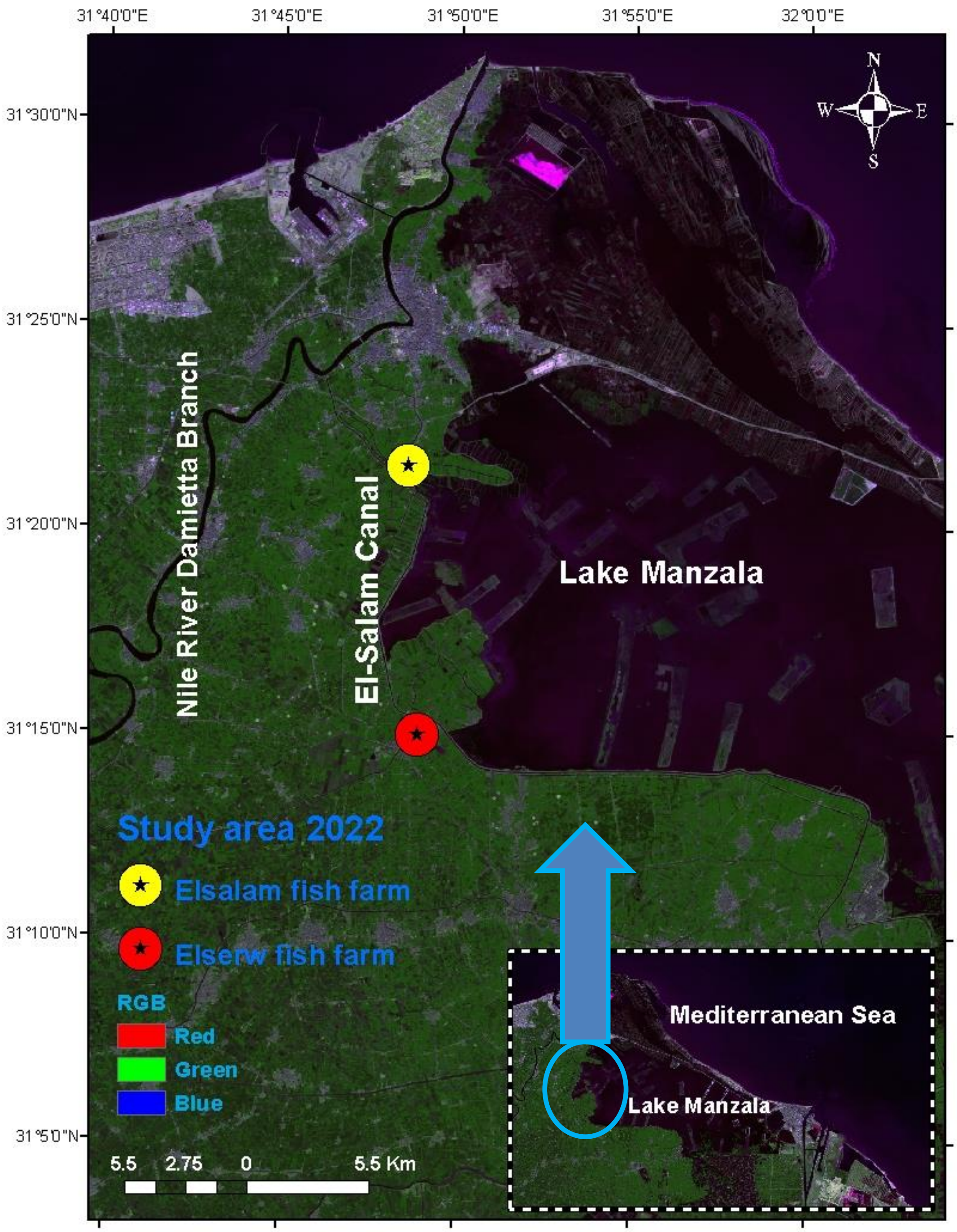


Fig. 1. Map of the study area. Inset: overview of Lake Manzala on the Mediterranean coast with a circle showing the area covered in this study. Main image: RGB image of Landsat-OLI 8 in 2022 for Lake Manzala. Elsalam fish farm (Bad aquaculture conditions) is marked by yellow stared circle, while Elserw fish farm (Good aquaculture conditions) is marked by red stared circle.

Both farms had a water depth of 2m, and stocked with the African catfish (*C. gariepinus*) with initial weight of 116.6±7.45g at the beginning of the farming season, which lasted for 6 months. Both farms receive their input water from the same source, which is mixed water between the El-Salam Canal and the drainage water that flows through the Elserw drain to Lake Manzala.

Elserw fish farm is nearly 35 acres of earthen ponds and facilities, and produces approximately 3 tons/acre from different freshwater fishes, like tilapia, mullets, carp, and the catfish. This study was conducted in 4 ponds, each pond is 1 acre area. Manufactured diet meals (3% of body weight regimes) were fed to the farmed fish, which ranged from 30-25% crude protein according to the age requirement. Water change was daily performed at a 10% change rate to maintain good water characteristics (Table 1).

Table 1. Water parameters of the ponds during sampling of the two studied fish farms in July 2022

Parameter	Farm1 (Elserw)	Farm2 (Elsalam)
Temp (°C)	32.2	33.4
PH	8.24	7.26
EC (mS/cm)	3.04	1.78
DO (mg/l)	6.4	2.3
NH_3(mg/l)	2.6	5.1

Elsalam fish farm is about 10 acres of earthen ponds, each pond is 1 acre area, and produces approximately 7-8 tons/acre. Monoculture type has been practiced there for only the catfish for many years. Poultry by-product meals were provided at 3% of the farmed catfish weight in the pond without any treatment or justification, which impacts water characteristics like smell and color. Water is rarely changed, which turned rapidly to deteriorated water (Table 1).

1. Sampling

Replicate water samples were collected using 2-L Ruttner bottles from the 1–1.5-m water depth ponds throughout the study period. Fish samples were freshly collected from the sampled ponds (4 earthen ponds in each farm) on both farms in July 2022.

All morphometric characters and meristic counts for each fish were recorded. The total weight (g) of the fish was immediately measured for all collected samples. The digestive canal was removed, weighed, and then preserved in a 5% neutralized formalin solution of the fish sample. Samples were labeled, and transported directly into an ice box to the laboratory for further analysis.

All hydrogen ion concentration (pH), electrical conductivity (EC), and water temperature (Temp) were immediately measured onsite using a portable calibrated multiparameter water quality meter (Model C8GoT Consort, Belgium). The water temperature from the water quality meter was validated with a 0.1°C graduated thermometer. The standard methods for the examination of water and wastewater described in the American Public Health Association **(APHA, 2005)** were used for the determination of all other measured parameters in the laboratory.

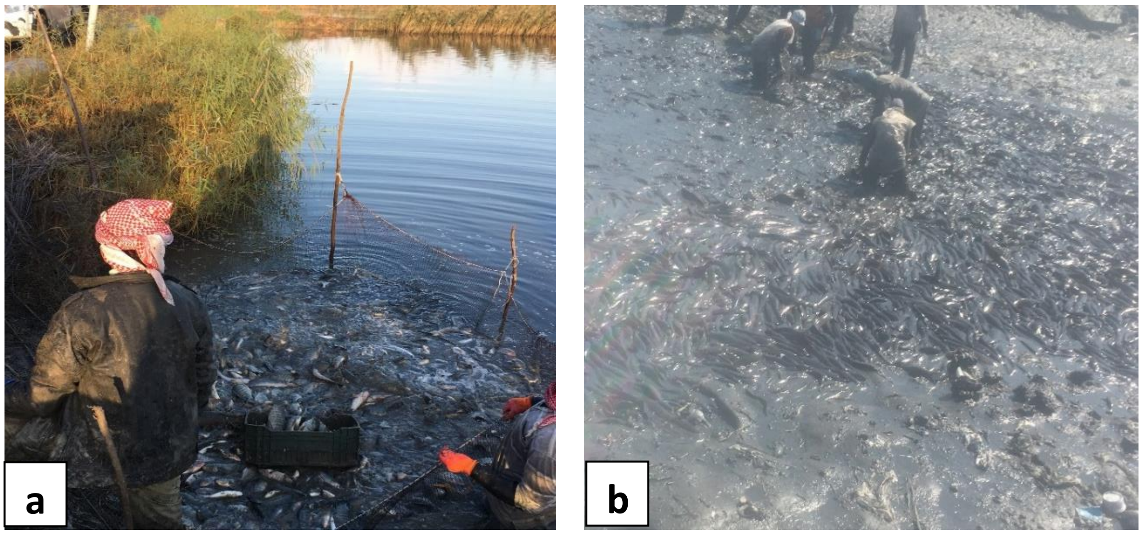


Fig. 2. Harvesting process of the two fish farms: **a**) Elserw fish farm with poly-culture type; **b**) Elsalam fish farm with monotype culture

2. Calculation of fish performance

Fish performance was evaluated for final weight (g), weight gain (g), weight gain (%), average daily gain (g), digesto-somatic index (%), specific growth rate (%Day^{-1}), and survival rate (%) as follows:

$$(a)\ Average\ daily\ gain\,(g) = \frac{W_2 - W_1}{t}$$

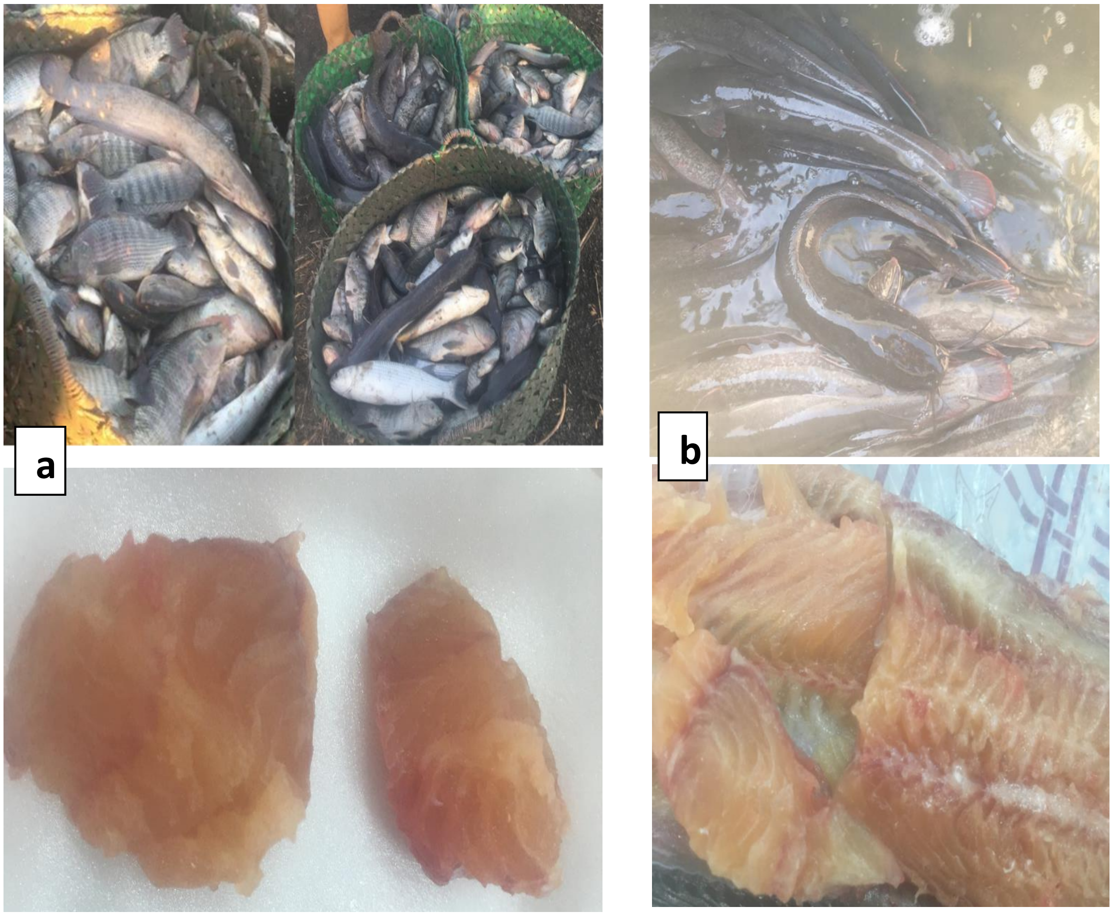
$$(b)\ Weight\ gain\,(\%) = \frac{W_2 - W_1}{W_1} X\,100$$

$$(c)\ Specific\ growth\,rate\ (\%\mathrm{Day}^{-1}) = \frac{\ln W_2 - \ln W_1}{t} X\,100$$

$$(d)\ \ Digesto\text{-}somatic\ index\,(\%) = \frac{Digestive\ tract\ weight}{W_2} \times 100$$

Where, W_1 = initial weight (g). W_2 = final weight (g). t = rearing duration (days).

$$(e)\ Survival\ (\%) = \frac{number\ of\ fish\ harvested\ X\ 100}{number\ of\ fish\ stocked}$$



$$(e)\ Survival\ (\%) = \frac{number\ of\ fish\ harvested\ X\ 100}{number\ of\ fish\ stocked}$$

Fig. 3. Final product after the harvesting process of the two fish farms: **a**) Elserw fish; **b**) Elsalam fish

3. Laboratory analyses

In the laboratory, the dorsal fish muscles were dissected, weighed, and immediately frozen at -20ºC for subsequent body composition for each sample alone.

3.1. Chemical composition of fish samples

Proximate analyses of the body moisture, protein, lipid, and ash were performed according to the standard of **AOAC (2012**) methods. Moisture content was determined by oven-drying a weighed wet sample at 105°C for 24h. Crude protein content was determined by the micro-Kjeldahl method (total nitrogen × 6.25). Crude lipid was determined by a Soxhlet method. Ash content was determined using a muffle furnace at 600°C for six hours. Values were expressed in percentages (%).

3.2. Blood sampling

Fish were fasted for 48 hours before sampling; blood samples were obtained from the caudal vein using 3ml syringe and divided into two tubes. The first aliquot was stocked in a heparinized tube for hematological assessment, while the second one was anticoagulant-free for biochemical estimation.

3.2.1. Hematological parameters

Hematological measurements were assessed within one hour of sampling for the first tube using a blood cell automated counter. White blood cell count (WBC), platelet count (Plat), hemoglobin level (H.G), red blood cell count (RBC), and hematocrit value (HCT) were estimated. Different blood indices such as mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), and mean platelet volume (MPV) were calculated.

3.2.2. Biochemical parameters

Anticoagulant-free samples were used for serum preparation by centrifugation for 20 minutes at 1207g within one hour of sampling, the sera samples were used for the determination of the total protein (g/l), albumin (g/l), globulin (g/l), glucose (g/l), nilirubin (g/l), creatinine (g/l), urea-N (g/l), triglycerides, cholesterol, glutamic – oxaloacetic transaminase (Got, U/mg protein), glutamic – pyruvic transaminase (Gpt, U/mg protein) on the same day with commercial kits. Absorbance values of samples and standards were measured using a UV spectrophotometer.

3.2.3. Histopathological examination

Specimens of liver, kidney, and muscle from both fish farms were fixed in 10% formaldehyde for Hematoxylin-Eosin staining technique and subsequently histopathological examinations. The specimens were washed under running tap water overnight, then dehydrated in ascending series of alcohol, processed through xylene-alcohol, and then cleared in two changes of xylene. They were transferred into a mixture of xylene and melted paraffin for 1 hour, and then into two pure paraffin changes, 30 minutes each for infiltration. The specimens were embedded in pure paraffin to form blocks. Serial sections were cut at a thickness of 5 microns using a rotary microtome. Sections were ready to be stained in hematoxylin and eosin.

4. Statistical analysis

All results were expressed as mean ± standard error (mean ± SE). All data were also subjected to paired comparison (t-test) to calculate the probability (*P*-value) indicating that there is no statistical difference between the treatments associated with the two fish groups. If $P \leq 0.05$, there are significant differences between the two groups. SPSS software (Release 14.0; SPSS, Chicago, IL, USA) was used.

RESULTS

Comparison between the catfish of Elserw fish farm, which exhibits good aquaculture conditions, and those of the Elsalam fish farm, which exhibits bad aquaculture conditions was presented statistically in the following tables.

1. Body composition analyses

The body composition analyses of the catfish muscles showed some differences in the body content of fish from both farms at $P\leq 0.05$ (Table 2).

Table 2. Proximate analysis of fish muscle (% wet weight basis) of the catfish (mean±SE) reared in two different environments, Farm1 (good environment) and farm2 (bad environment)

	Farm1 (Elserw)	Farm2 (Elsalam)	*t*-test	*P*-value
Moisture (%BW)	76.90 ± 0.68	66.94 ± 1.50	-6.65	0.0219 *
Protein (%BW)	15.05 ± 0.49	16.78 ± 1.00	2.99	0.0962
Lipid (%BW)	6.16 ± 0.56	14.62 ± 1.27	10.65	0.0087 **
Ash (%BW)	0.83 ± 0.11	0.74 ± 0.08	-0.465	0.6879

Values with one asterisk (*) are statistically significant at $P\leq 0.05$.
Values with two asterisks (**) are statistically highly significant at $P\leq 0.05$.

Moisture showed a statistically significant difference ($P\leq 0.05$) between fish of both farms, where it was higher in Elserw catfish than in Salam catfish (76.90, 66.94%, respectively). However, differences in lipid content were highly significant at $P\leq 0.05$, which showed an indirect relationship with moisture content. The catfish of Elsalam fish farm was fattier than those of Elserw fish farm (14.62, 6.16%, respectively). Differences between protein content and ash were not significant at $P\leq 0.05$.

2. Growth performance of fish

The growth parameters of the catfish, including final weight (g), weight gain (g), average daily gain (g), and digesto-somatic indices (%) were not significant between both farms ($P\leq 0.05$). However, specific growth rate (%Day^{-1}) and survival rate (%) were significantly improved ($P\leq 0.05$) in Elserw farm compared to Elsalam farm (Table 3).

Table 3. Growth parameters of the catfish (mean ± SE) reared in two different environments, Farm1 (good environment) and farm2 (bad environment)

	Farm1 (Elserw)	**Farm2 (Elsalam)**	***t*-test**	***P*-value**
Final weight (g)	1706.67 ± 162.49	1970.00 ± 135.35	3.823	0.062
Weight gain (g)	1590.00 ± 155.18	1853.33 ± 128.23	3.823	0.062
Weight gain (%)	1337.78 ± 50.01	1586.67 ± 38.84	3.000	0.095
Average daily gain (g)	7.57 ± 0.74	6.86 ± 0.47	-1.165	0.364
Specific growth rate (%Day^{-1})	1.27 ± 0.02	1.05 ± 0.01	-8.039	0.015 *
Digesto-somatic index (%)	1.90 ± 0.20	1.47 ± 0.06	-1.262	0.334
Survival rate (%)	98.33 ± 0.20	93.33 ± 0.39	-6.546	0.022 *

Values with one asterisk (*) are statistically significant at ($P \leq 0.05$).

However, the final weight of the catfish from Elserw farm (Good aquaculture condition) was less than that of samples of Elsalam farm (bad aquaculture condition), showing much better average daily gain (g) and digesto-somatic indices (%), respectively.

3. Complete blood analyses

3.1. Hematological parameters

The present study showed that the hematological parameters were significantly affected ($P \leq 0.05$) by aquaculture conditions (Table 4). White blood cells (WBC), hemoglobin (H.G), red blood cells (RBC), hematocrit (HCT), mean corpuscular hemoglobin concentration (MCHC), and mean platelet volume (MPV) were significantly higher ($P \leq 0.05$) in the catfish of Elserw farm than in Elsalam farm. Conversely, the platelet count was larger in Elsalam farm catfish than in Elserw catfish, while the difference was not significant at $P \leq 0.05$. However, the difference between H.G and MCHC of catfish from both farms was highly significant ($P \leq 0.05$).

Table 4. Hematological responses of the catfish (mean ± SE) reared in two different environments, Farm1 (good environment) and farm2 (bad environment).

	Farm1 (Elserw)	Farm2 (Elsalam)	*t*-test	*P*-value
WBC*10^3/ul	70.71 ± 1.55	32.44 ± 2.87	-10.374	0.0092 **
Plat *10^3/ul	8.00 ± 1.15	9.67 ± 0.88	0.822	0.4975
H.G g/dl	16.27 ± 0.37	8.60 ± 0.61	-7.903	0.0156 *
RBC 10^6/ml	3.10 ± 0.15	1.48 ± 0.12	-6.157	0.0254 *
HCT%	50.17 ± 2.54	22.23 ± 1.09	-8.118	0.0148 *
MCV fl	161.87 ± 3.01	151.07 ± 5.36	-1.390	0.2990
MCH pg	58.10 ± 1.47	52.50 ± 1.32	-2.545	0.1259
MCHC g/dl	38.50 ± 0.92	32.50 ± 0.96	-11.547	0.0074 **
RDW-CV %	12.90 ± 0.42	9.93 ± 0.93	-2.674	0.1160
RDW-SD FL	87.43 ± 4.47	63.00 ± 7.59	-2.472	0.1321
MPV	6.33 ± 0.38	5.43 ± 0.20	-4.500	0.0460 *
PDW	4.37 ± 0.32	10.71 ± 8.06	0.814	0.5012

Values with one asterisk (*) are statistically significant at ($P \leq 0.05$).

Values with two asterisks (*) are statistically highly significant at ($P \leq 0.05$).

3.2. Biochemical parameters

The biochemical parameter values of the catfish in both farms were mostly not significant ($P \leq 0.05$), except for urea-N, which was significantly higher in Elsalam catfish than in Elserw catfish samples (Table 5). Total blood protein, albumin, globulin, glucose, and cholesterol values were higher in Elserw catfish (which represents the good aquaculture condition), while bilirubin, creatinine, triglycerides, Gpt, and Got values were higher in the catfish of Elsalam farm, which reflects the effect of the bad aquaculture condition.

Table 5. Biochemical parameters of the catfish (mean ± SE) reared in two different environments, Farm1 (good environment) and farm2 (bad environment)

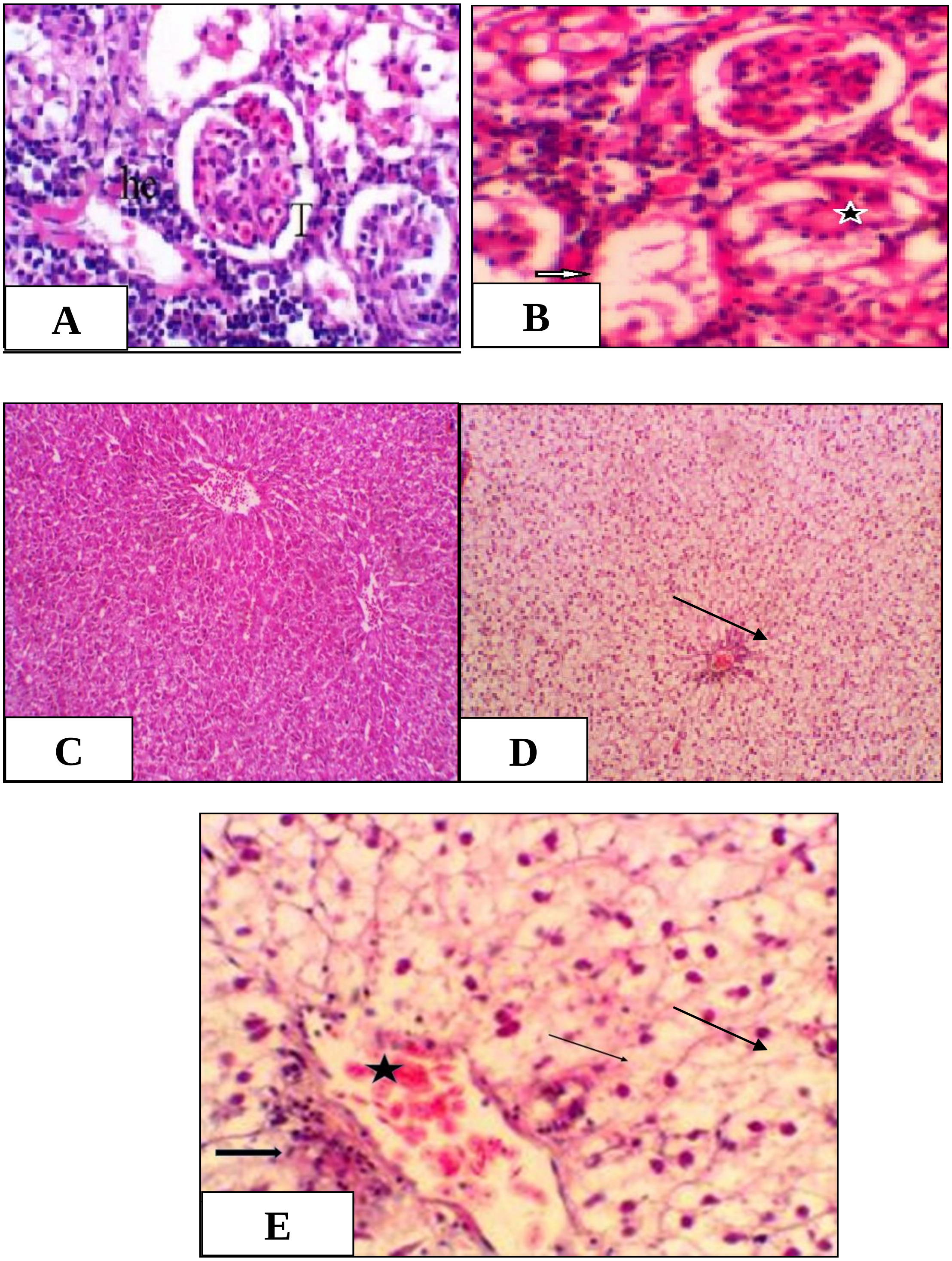
	Farm1 (Elserw)			Farm2 (Elsalam)			*t*-test	*P*-value
Total protein (g/l)	5.34	±	0.83	4.77	±	0.32	-0.985	0.4284
Albumin (g/l)	1.19	±	0.09	1.11	±	0.04	-1.437	0.2873
Globulin (g/l)	4.15	±	0.75	3.74	±	0.28	-0.848	0.4856
Glucose (g/l)	178.06	±	14.73	167.53	±	28.73	-0.281	0.8051
Bilirubin (g/l)	7.53	±	4.21	13.17	±	0.35	1.237	0.3418
Creatinine (g/l)	0.64	±	0.03	0.66	±	0.02	0.961	0.4380
Urea-N (g/l)	3.09	±	0.21	3.80	±	0.10	6.335	0.0240*
Triglycerides	111.41	±	6.89	130.29	±	29.45	0.520	0.6548
Cholesterol	724.59	±	176.45	368.45	±	76.71	-3.177	0.0864
Got (U/mg protein)	217.60	±	58.73	265.37	±	35.20	0.511	0.6620
Gpt (U/mg protein)	20.00	±	4.13	28.37	±	2.86	1.245	0.3393

Values with one asterisk (*) are statistically significant at $P \leq 0.05$.

4. Histological examination

Histological comparison between the catfish from both farms showed a very distinct difference. The posterior kidney of catfish from good aquaculture conditions (Elserw fish farm) exhibited normal renal tubules with normal hematopoietic tissue in between (Fig. 3A). In affected diseased catfish from bad aquaculture conditions (Elsalam fish farm), the posterior kidney showed thinning of tubular epithelium and shedding of tubular epithelium in their lumina (Fig. 3B).

The normal liver of the catfish from good aquaculture conditions showed normal histological appearance of hepatocytes (Fig. 3C). While, in affected catfish from bad aquaculture conditions (Elsalam fish farm) hepatopancreas exhibited diffuse, marked hepatic vacuolation (Fig. 3D), with congested blood vessel and focal perivascular leukocytic aggregations (Fig. 3E). Muscles of catfish from Elserw fish farm exibited myofibers in normal appearance (Fig. 3F). Whereas, in diseased muscles of catfish of Elsalam fish farm showed edema with widely separated hyalinized compressing muscle fiber beside dilated blood vessels and influx of leukocytic cells (Fig. 3G).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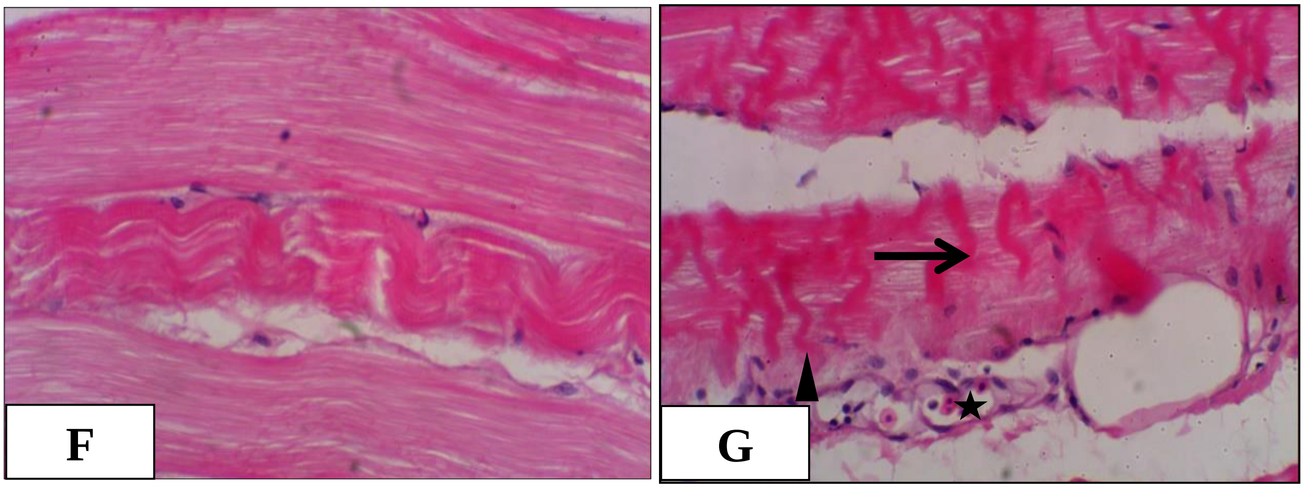

Fig. 4. Representative photomicrograph of kidney, liver, and muscle of the catfish representing the normal and the diseased tissues from good aquaculture conditions and bad aquaculture conditions, respectively. **A.** Normal kidney showing the normal histological appearance of most renal tubules (T) and hematopoietic tissue (he) H&E (100x). **B.** The kidney in the diseased catfish showing thinning of tubular epithelium (arrow) and shedding of tubular epithelium in their lumina (star) H&E (100x). **C.** Normal liver showing the normal histological appearance of hepatocytes, H&E, (100x), while **D.** in the affected hepatopancreas there was diffuse, marked hepatic vacuolation (thin arrow) H&E (100x). **E.** Higher magnification of hepatopancreas tissue the liver showing vacuolation replacing the hepatic cytoplasm pushing nucleus peripherally (thin arrow) with congested blood vessel (star) with focal perivascular leukocytic aggregations (thick arrow), H&E (400x). **F.** Normal muscle of catfish from good aquaculture conditions showing the normal histological appearance of myofibers, H&E, (100x). **G.** While, in diseased muscle of catfish from bad aquaculture conditions, edema (star) widely separated a hyalinized compressing muscle fiber (thin arrow) with dilated blood vessels and influx of leukocytic cells (arrow head), H&E. (100x).

DISCUSSION

The potential of aquaculture practices in fish farms can be evaluated based on the growth performance, hematological, biochemical, and histological parameters. Due to the feeding of Elsalam fish farm on poultry by-product meals and chicken viscera, which have high loads of bacteria, the water of the pond was highly deteriorated **(Ntsama *et al*., 2018)**. This decreases the pH of the pond water and enhances the bacterial activity collected with the degradation of the proteins contained in the meals fed to fish on this farm, which consequently turned to ammonia **(Padmavathi *et al*., 2012; Zhang *et al*., 2021)**. These processes exhaust the dissolved oxygen (DO) and might be the reason for the high ammonia content in Elsalam fish farm water. For this reason catfish can grow well even in this deteriorated water, where DO decreases under the optimum level (5ppm) and ammonia exceeds the permissible limits **(Oyewole *et al.*, 2009; Uzochukwu *et al*., 2023)**. This is due to the atmospheric oxygen breathing mechanism of the catfish through their skin and the functionally developed respiratory organs, which enable them to tolerate low DO concentrations **(Peteri *et al*., 1992; Abd-Elmaksoud *et al*., 2008)**. However, feeding efficiency and growth rate were severely affected by exposure to ammonia concentrations above 90µm **(Schram *et al.*, 2010; El-Sikaily and Shabaka, 2024)**.

The food type can also alter the growth performance, the enzymatic profile, and the immunity of the exposed fish **(Logambal & Michael, 2000; Abdel-Hay *et al.*, 2020)**. It may cause behavioral, biochemical, hematological, and histopathological changes, which may lead in some cases to mortality **(Omoniyi *et al*., 2002; Abalaka *et al*., 2010; Chandel *et al*., 2024)**.

The body composition analyses of the catfish muscles were affected by the aquaculture conditions. The catfish reared in Elserw fish farm (good conditions) attained significantly higher water content and significantly lower lipid content than the fish reared in Elsalam fish farm ($P \leq 0.05$). This inverse relationship between the muscle water content and the lipid content may indicate fish exposure to starvation during the culturing cycle, which accelerates lipid catabolism as the first energy source to survive during starvation **(Tan *et al.*, 2009; Chor *et al.*, 2013)**. Additionally, protein content was relatively decreased in Elserw fish farm than Elsalam fish farm, while the muscle lipids showed a greater decline than did muscle proteins, which means that the starvation periods were not prolonged in Elserw fish farm **(Gou *et al*., 2023)**. Indeed, Elserw fish farm provides manufactured meals to fish that meet the nutritional requirements for the catfish, even if the food quantities are less than those provided in Elsalam fish farm.

These feeding practices together with the good water quality also explain the good growth performance and high survival of fish of Elserw fish farm, which was significantly higher than the catfish of Elsalam farm ($P \leq 0.05$). The lower growth rate, lower weight gain, and lower average daily gain of catfish of Elsalam fish farm may be a result of undigested or poorly utilized poultry by-product meals or chicken viscera provided to fish on this farm. This agrees with the results reported by **Chor *et al.* (2013**), who reported that the poultry by-product meals were poorly digested by the catfish. Moreover, **Hertrampf and Piedad-Pascual (2000)** reported that the poultry by-product meals lack certain essential amino acids, viz. lysine, methionine, and histidine needed for better fish growth. This growth retardation may be referred to as the imbalanced amino acid content of the diet without fishmeal, while the replacement of fishmeal instead of poultry viscera meal in diets may improve the growth performance and feed utilization efficiency.

The survival rate is one of the major concerns of the fish farmers. Feeding can be harmful to the fish, and in many cases was the main cause of mortalities. The farmers of the catfish used to apply worse feeding practices to gain more profit, however, this manner caused the death of fish and pollution of water by the pathogenic microbial load in diet meals. The present study revealed that good aquaculture conditions together with a proper feeding process achieve the best survival of the catfish **(Abdel-Hay *et al.,* 2020)**. The survival rate in Elserw fish farm exceeds 98% due to the adjusted feeding quality and quantity, which enhanced growth and improved the aquaculture conditions **(Abdel-Hay *et al.,* 2020; Jimoh *et al.,* 2022)**. Conversely, the low survival rate in Elsalam fish farm explains the bad effect of the unadjusted feeding practice, which may contain high lipid content in poultry viscera (32%), as reported by **Toutou *et al.* (2018)**.

The hematological and biochemical parameters are good indicators of the health status and welfare of fish **(Fazio, 2019; Jimoh *et al.,* 2020; Jimoh *et al.,* 2022)**. The comparison between hematological and biochemical examination of the catfish from both farms showed that good aquaculture conditions have a positive impact on the catfish. The high values of hemoglobin (H.G), red blood cells (RBC), hematocrit (HCT), and mean corpuscular hemoglobin concentration (MCHC), and mean platelet volume (MPV) of catfish reared in Elserw fish farm might be referred to the good physiological status accompanied by the good efficiency (weight gain, and growth rate), more fish activity owing to the good oxygenation of the different tissues, and consequently enhanced general health and welfare **(Owolabi, 2011; Acharya & Mohanty, 2014; Hoseini *et al.,* 2019; Abdel-Hay *et al.,* 2021)**. The increase in the white blood cell (WBC) count of Elserw catfish implies the improved immune system of the catfish reared in good aquaculture conditions **(Fazio, 2019)**, however the larger platelet count of Elsalam farm catfish than the count in Elserw catfish revealed that the fish in Elsalam farm, which represents in this study the bad aquaculture condition, are subjected to pathogens and inflammation than those of the good aquaculture condition, which generate the platelets under these unhygienic conditions **(Yeung *et al.,* 2018)**.

The low levels of total blood protein, albumin, and globulin in the catfish of Elsalam farm, which exhibits the bad aquaculture conditions, may be related to proteolysis and metabolic process, and/or liver or kidney damage of the catfish subjected to chronic harsh environmental conditions **(El-Boshy *et al*., 2014)**. Plasma globulin improved in Elserw farm fish under good aquaculture conditions, which plays a varied role in fish immunity and the antioxidant capacity of fish **(Gerwick *et al*., 2002; Abdel-Rahim *et al*., 2023)**. On the other side, the elevated level of bilirubin in the catfish of Elsalam farm may reflect the liver dysfunction and RBCs destruction under this bad condition. This is similar to what happened to the kidney under the same condition, which led to an increase of creatinine in the blood of the catfish of Elsalam farm.

The significantly increased urea in the serum of the catfish of Elsalam farm indicates that catfish was subjected to continuous high levels of pollutants in this environment, affecting the glomerular filtration rate, causing disintegration of epithelial cells, and breakdown of Bowman's capsules. Moreover, the proteolysis process may induce urea secretion in the blood serum of the catfish under these bad conditions. However, the relatively low urea levels in both bad and good aquaculture conditions suggest that the African catfish can withstand the fluctuations in environmental conditions, which is considered an additional attribute of its aquaculture potential **(Okechi, 2004; Owolabi, 2011)**.

Like most of the aquaculture ponds in this region, Elsalam farm exhibited both organic and biological pollution due to the worse feeding practices resulting in deteriorated water **(El-Mezayen *et al*., 2018)**. These severe conditions lead to hypothyroidism, which in turn increases the level of triglycerides in plasma. This is associated with high concentrations of bilirubin, indicating liver dysfunction, as the liver requires adequate levels of thyroid hormones to optimally perform its metabolic functions **(Gaber *et al.*, 2013; Yorke, 2022)**. Hypothyroidism is well known for its influence on body weight, it is usually associated with an increase in body weight, caused by oedema, which may lead to toxic hepatitis **(Iwen *et al*., 2013)**.

On the other hand, the raised triglyceride level was accompanied by reduced cholesterol level, which is typically metabolic syndrome, which reflects usually hepatic disorders, cardiometabolic risk, and may result in mortality **(Iwen *et al*., 2013)**. A similar trend of increasing triglyceride levels with decreased cholesterol levels was observed by **Elarbany *et al* (2019**); however, most studies reported increasing triglycerides with increasing cholesterol **(Abdel-Hay *et al*., 2021; Jimoh *et al*., 2022)**. The high concentration of liver enzymes in the catfish of Elsalam farm reflects the effect of hypothyroidism accompanied by hepatocyte damage in the African catfish, as liver enzyme activities increased significantly in both hyperthyroidism and hypothyroidism **(Ajala *et al.*, 2013; Elarabany *et al*., 2019)**. All biochemical parameters of the catfish in both conditions, whether good or bad, were in the normal reference range, which indicates the ability of the African catfish farming aptitudes.

The harsh circumstances of bad and consequently unhygienic aquaculture conditions are the core triggering causes of initiation for pathological changes in different organs of fish such as liver, kidney, and muscle **(Jansson & Vennerström, 2014; Chong, 2022)**.

Kidney exposed to unhygienic conditions in Elsalam farm showed moderate hyaline cast in the lumen of renal tubules; homogenous structure with less eosinophilic material in the lumen of renal tubules with thinning of tubular epithelium, as similar results were reported in previous studies **(Jimoh *et al.*, 2015; Aly *et al*., 2020; Ghonimi, 2022)**.

The hepatopancreas is the site of detoxification of all types of bacterial toxins and fungal toxins **(Vogt, 2020)**. The cytological examination of the hepatopancreas in infected fish from Elsalam farm revealed degenerative changes, including mononuclear cell infiltration, which corresponds to observations made by **Abdelhamed *et al.* (2017)**. They described similar degenerative changes and mononuclear cell infiltration in the liver of infected fish. The present histopathological findings indicate hepatic cell destruction, as confirmed by biochemical analyses. Fatty changes in the hepatocytes, characterized by the presence of sharply outlined vacuoles, were observed. These results are likely due to the unhygienic conditions on Elsalam fish farm, increasing the permeability of blood proteins (such as albumin) **(Gómez-Zorita *et al.*, 2019; Phuc *et al.*, 2022)**. Liver tissue damage occurs when it is repeatedly exposed to toxicants. Pathological changes in the liver and kidneys have been linked to the release of toxins and extracellular products, such as hemolysin, protease, and elastase, leading to rapid death due to organ failure **(Abdel-Latif *et al*., 2022)**. Muscle tissue acts as the first line of natural defense; however, unhygienic conditions break down this barrier damaging all internal organs **(Zhao *et al.*, 2020)**. The destruction of the myofibrillar apparatus can be attributed to the unfavorable conditions of Elsalam fish farm, which aligns with the findings of **Evgen'eva *et al*. (2000)**.

CONCLUSION

Aquaculture conditions, including water and feeding practices, produce complex effects on the general physiology, quality, and quantity of catfish, in terms of body composition (water and lipid), growth performance, survival rate, hematological parameters, and histopathology. Most of these parameters were enhanced under good aquaculture conditions in Elserw fish farm ($P \leq 0.05$). Nevertheless, unexpected enhanced weight gain and muscle protein of catfish were observed in bad aquaculture conditions represented by Elsalam fish farm, which may be related to the biological habits of the catfish.

Conflict of interest

The authors declare that there is no conflict of interest.

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