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Seasonal Changes in Nutrient Composition and Biochemical Markers of Toxicity of Fish Samples from Urashi River, Nigeria

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Abstract
Oil and gas prospecting generate pollutants that are toxic to aquatic organisms. Orashi/Urashi River flows along the oil prospecting sites of the Niger Delta region in Nigeria. Effects of petroleum pollution on two fish species (*Oreochromis niloticus* and *Clarias gariepinus*) from Urashi River which flows along four communities (Mmahu, Abacheke, Opuoma communities in Ohaji/Egbema L.G.A) and Anambra (Ogwuaniocha, Ogbaru L.G.A) states of Nigeria, were evaluated in both wet and dry seasons, using liver function parameters, lipid profile indices and histopathology of selected organs. Standard biochemical and histopathological procedures were employed for all the analyses. Nutrient composition of the fish samples showed that crude protein, carbohydrate, and energy values were: 21.25%, 22.27% and 186.97 Kcal respectively for wet-season *C. gariepinus* from Ogwuaniocha. The values were significantly ($p<0.05$) higher than that of all other fish samples. A marker of liver damage-Aspartate aminotransferase (AST) activity (35.05;123.93; and 144.33 U/L) of fish samples was significantly ($p < 0.05$) higher in the dry season. Aspartate aminotransferase (ALT) activities of *C. gariepinus* (144.33U/L) and *O. niloticus* (123.93 U/L) were significantly ($p<0.05$) higher in the dry season relative to the rainy season. Alkaline phosphatase (ALP), total protein, and globulin concentrations did not vary significantly ($p>0.05$) in all the fish samples. Cholesterol, triglyceride, and high-density lipoprotein cholesterol (HDL-C), levels of *O. niloticus* were significantly ($p>0.05$) lower in the wet season. The gill, muscle and liver histology showed mild to marked lymphocyte and fibroblast infiltrations. In contrast, the gill showed diffused lamellar absence, marked necrosis, and depletion of epithelial cells lining the filaments, which were more prominent in the dry season. The toxic impact of the petroleum hydrocarbon on the fish samples were higher during the dry season. This could be due to the increased hydrocarbon concentration occasioned by reduced water volume in the dry season.
Keywords: Climate change, Fish, Lipid profile, Liver function, histopathology, Pollution, River, Nigeria

Introduction

The Niger Delta area of Nigeria is renowned for its extensive involvement in oil exploration endeavours. It is the second largest delta globally, covering over 400 km of coastal line that reached the starting point of the Imo River. It is the largest wetland in Africa is composed of swamps, rivers, creeks and estuaries (World Bank, 2011). It serves as a habitat for various species of aquatic organisms, including fish (Iyayi, 2004). The pursuit of oil in the Niger Delta area has led to serious environmental challenges that affect living and non-living things in the ecosystem. The Department of Petroleum Resources (DPR) reported more than 4500 oil spill incidences, which accounts for approximately 150,000 barrels of oil in Nigeria between 2010 and 2016 (DPR, 2016). These oil spillages have led to contamination of waterbodies, fish and other aquatic organisms (Ele, 2022). Elum *et al*. (2016) reported that oil pollution that resulted in the death of fish and loss of important aquatic species has significantly contributed to food insecurity in the Niger Delta area. Crude oil products and their derivatives enter the body of aquatic organisms such as fishes, molluscs and crustaceans through the food network and accumulate in the liver and gallbladder (Chorehi *et al*., 2013). Oil pollution alters the colour, odour and taste of fish even at minimal concentrations (Nnaji *et al*., 2021). Agliardi *et al*. (2017) reported that oil spills impact fish even after mopping up oil in water bodies. Some aquatic organisms ingest some toxic substances from oil, which may not lead to their deaths, but can cause varying health risks to humans and other animals that consume them (Anejionu *et al*.,

2015).

Oil and gas exploitation products consist of basically different hydrocarbons, such as as alkanes, alkenes and aromatics. These compounds show varying degrees of toxicity when they are introduced into water bodies. Other hydrocarbons, such as benzene, toluene, ethyl benzene and xylene which are collectively known as BTEX are more toxic because they are more soluble and can diffuse readily into different organisms (Wang *et al*., 2011). They also contain heavy metals that are recalcitrant (Onwuteaka, 2016). These compounds pose health risks when they seep into water bodies.

Fish serves as a crucial contributor of animal protein in the dietary intake. In addition to being a rich source of essential amino acids, it also contains non-essential amino acids, ω-3 polyunsaturated amino acids, as well as eicosapentaenoic acid and docosahexaenoic acid (Ayanda *et al*., 2019; Strateva *et al*., 2021). Polyunsaturated amino acids in fish plays a vital role in mitigating the risk of cardiovascular diseases, rheumatoid arthritis and cancer. Fish contains vitamins A and D and micronutrients such as iron, selenium, zinc and phosphorus (Tilami and Sampels, 2017). The minerals in fish help regulate acid-base and water balance, and enhance haemoglobin, as well as development of bones and teeth. Also, minerals act as catalysts for numerous biological processes within the human body (Raatz *et al*., 2013). The majority of the fish consumed by the urban dwellers are sourced from the rural fish farmers. Khan *et al.* (2019) and Makwinja and Geremew (2020) reported that some fish tissues contain heavy metals. Accumulated heavy metals in fish tissues can be transferred to consumers through the food chain (Naghipour *et al*., 2016). Communities around the Urashi River engage in fishing activities as a means of livelihood aside crop production. The Urashi River is periodically contaminated by oil spills. Nnaji *et al*. (2022) reported the presence of varying concentrations of hydrocarbons as well as oil and grease in the water and sediment samples of Urashi River in the dry and wet seasons. These pollutants could alter various nutrients in fish and cause damage to the organs of fish samples. The study is therefore aimed to assess seasonal changes in nutrient composition and biochemical markers of toxicity in fish samples from the Urashi River in the Niger Delta area of Nigeria.

Materials and Methods

Study area

The Urashi River/Orashi River/Ulasi River) is situated in the lower Niger River basin. It flows across Anambra, Imo, Bayelsa and Rivers States (Fig. 1). The area was chosen for this study because about one-third of the oil wells in Imo and Rivers states are located around the Urashi area. The major occupations of the rural dwellers around the area include fishing, farming and trading.

Sample collection

Fish samples were collected with the help of fishermen using local fishing gear (cast net, mali trap and long line). Two fish species (*Oreochromis niloticus* and *Clarias gariepinus*) were collected in triplicates along the Urashi River at Mmahu, Opuoma, and Abacheke in Ohaji/Egbema LGA and from Ogwu Aniocha in Ogbaru LGA in both wet and dry seasons. The coordinates of the sampling sites were measured with the aid of a GARMIN global positioning system (GPS) instrument (Table 1). The random sampling method was used in the selection of the fish samples used for analysis. The fish were transported in cool water with adequate ventilation to the laboratory within 3 hours of harvest. Ethical approval for this study was obtained from the University Animal Ethics Committee with reference number: MOUAU/CVM/REC/201918.

Determination of proximate composition

Fresh fish samples were used for proximate analysis. Proximate composition was determined using the procedure outlined by AOAC (2005). Moisture content, protein, fat, ash and crude fibre, were determined. The carbohydrate content was calculated by difference, and the energy value was determined using the Atwater factor (AOAC, 2005).

Determination of biochemical parameters

Fish samples were properly restrained in a dorsoventral position, and approximately 2 ml of blood from the caudal vasculature using a 5 ml syringe with a 22-gauge needle, then transferred into plain sample bottles. Thereafter, the plain bottles were placed in a slant position for about 1 hour to allow the blood to clot and retract. The blood samples were centrifuged at 3000 rpm for 10 minutes. The serum was then transferred into plain sample bottle and stored in a refrigerator at 4°C. The samples were analyzed within 48 hours of collection. A commercially available reagent kit (Randox Diagnostic Laboratories, United Kingdom) was used to measure the levels of high-density lipoprotein cholesterol (HDL-C), total cholesterol, triglyceride, total protein, albumin, globulin and the activities of the enzymes alanine aminotransferase (ALT), aspartate aminotransferase (AST), and alkaline phosphatase (ALP) in the serum (according to the manufacturer's instruction). Using Fried Ewald's equation, the serum levels of low-density lipoprotein cholesterol (LDL-C) and very low-density lipoprotein cholesterol (VLDL-C) were determined:

$$\mathrm{LDL-C} = \mathrm{TC} - \mathrm{HDL-C} + \mathrm{TAG}/5;$$

$$\mathrm{VLDL-C} = \mathrm{TAG}/5,$$

(Krishnaveni and Gowda, 2015).

Histopathological examination of fish organs

The fish gills, muscle and liver were excised and fixed in 10% formalin before undergoing a routine histological procedure that included dehydration in ethanol at varying concentrations, clearing in xylene, and embedding in paraffin wax. Leitz microtome model 1512 was used to cut sections to 5 µm thickness. They were stained for light microscopy with haematoxylin and eosin (Bancroft and Stevens, 1990). Photomicrographs were taken using an Olympus microscope and a Motican 2001 camera (Motican UK).

Statistical analysis

Data from the study were analyzed using Statistical

Package for Social Sciences (SPSS) version 21. Descriptive statistics were applied, and the results were presented as means ± standard deviations from triplicate determinations. One-way analysis of variance (ANOVA) was used in data analysis and the Duncan multiple range test was used to separate and compare the significant means at a 95 % confidence interval.

Results and Discussion

The GPS coordinates of the locations and sampling points are detailed in Table 1. Figure 1 shows the area under study.

Fish samples

Some of the fish samples were not available despite efforts made by the fishermen in the wet and dry seasons of the year to collect them. Table 2 shows the availability of fish samples from the four locations used for the study. The results indicate that it was difficult to obtain the fish samples required for analysis, both in the wet season and in the dry season. Catfish were found in the Ogwuaniocha and Abacheke locations only during the dry season while Tilapia (*Oreochromis niloticus*) was not found at all. Both catfish and tilapia were unavailable at the Mmahu location during the dry season. They were also unavailable in Abacheke, Opuoma and Ogwuaniocha during the wet season. This observation supports the perception of fish farmers in the area that oil exploration activities have significantly reduced the fish population in the Urashi River.

Proximate composition

Fish proximate composition is presented on Table 3. The moisture contents of the *Clarias gariepinus* (catfish) in the dry season were higher than in the wet season. The moisture content of catfish in both seasons (wet and dry seasons) ranged between 72.62 – 75.95% while that of tilapia was similar and ranged between 53.26-53.79%. The crude protein content of the catfish samples was similar in both seasons ranging between 14.77 and 21.25%. The Ogwuaniocha sample was significantly ($p > 0.05$) higher in protein when compared to the other fish samples. Crude protein content of dry season tilapia (14.98 %) was lower than that of wet season (19.99 %) ($p > 0.05$). Wet-season fish samples had the highest fat content of 1.55% and 1.76% for catfish and tilapia respectively. All the fish samples had similar crude fibre contents ($p > 0.05$). The ash content of all the fish samples in the dry season (1.37-1.93 %) was higher than those of the wet season (0.95 and 1.06 %). Catfish carbohydrate composition ranged between 6.59-22.27% while that of tilapia was 6.78-23.89%. The energy value of wet season catfish (113.31 kcal) was higher but statistically like those of dry season except that of Ogwuaniocha (186.97 kcal) which was significantly ($p > 0.05$) higher than all. Wet-season tilapia had a significantly ($p > 0.05$) increased energy value compared to that of the dry season. Total petroleum hydrocarbon, total hydrocarbon content and oil and grease of the Urashi water sample from Ogwuaniocha were significantly higher than those of Mmahu, Opuoma and Abacheke respectively for both wet and dry seasons (Nnaji et al., 2022), however, the crude protein (21.25%) and energy value (186.97) of the catfish from the same location (Ogwuaniocha) were significantly higher than those of other locations. Fish are good bioindicators of water pollution (Pérez-Iglesias *et al.,* 2023). Fish samples with low-fat content had high moisture content (Jim *et al*., 2017). Changes in seasons alter the fat content of fish samples (Akter *et al*., 2020). High moisture content favours microbial degradation of nutrients and reduces shelf life. The moisture content of catfish obtained in this study is like the value of 73.67% reported by Olaniyi *et al*. (2016) for catfish samples. Ash content obtained in this study is low compared to 2.10-3.67 %and 2.33-4.79% reported for wild and cultured catfish (Obaroh *et al.,* 2015).

Liver function parameters

Table 4 presents the result of liver function parameters of fish samples. Aspartate aminotransferase (AST) activity of wet season catfish was like that of the dry season except that of Ogwuaniocha (123.93 U/L) which was significantly ($p > 0.05$) higher. Dry-season tilapia had higher enzyme activity (144.33 U/L) ($p>0.05$) than wet-season tilapia (27.60 U/L). Alanine aminotransferase (ALT) activity of wet season catfish was like those of dry season, ranging between 7.57-11.65 U/L while that of wet season tilapia was significantly ($p > 0.05$) lower than that of dry season ranging between 5.92-24.77 U/L. Alkaline phosphatase activity of all the fish samples from the wet season was similar to those of the dry season as well as total protein and globulin concentrations. The albumin concentration of wet season catfish was similar to those of dry season except for Abacheke catfish which was significantly ($p< 0.05$) lower. Biochemical analysis serves as a veritable tool for assessing pollution in the ecosystem and subsequent alterations over time (Mansour and Sidky, 2003). Blood biochemical parameters and organ histology are reliable indices for assessing the effect of stress factors on fish (Šimková *et al*., 2015). Liver function enzyme activities are used to assess water pollution in fish (Kim *et al.,* 2008). Liver metabolites and their enzymes are usually released following disturbances in liver tissue (Chang *et al*., 2021). In this study, aspartate aminotransferase (AST) activity in catfish for wet season catfish (Mmahu) and dry season (Abacheke and Opuoma) decreased significantly. Also, AST and alanine aminotransferase (ALT) activities of dry season tilapia were significantly ($p>0.05$) increased. AST values of >36 for adults and >40 for children are indicative of poor liver function. The activity of alanine aminotransferase (ALT) and alkaline phosphatase (ALP) activities as well as total protein, albumin and globulin concentrations of all the fish species in both wet and dry seasons did not differ statistically ($p< 0.05$). These trends could have been induced by oxidative stress arising from pollutants in the Urashi River. ALT values were lower than the threshold (>100U/L) indicating severe liver disease. Varying concentrations of cadmium, lead and iron were detected in the water and fish samples from Urashi River in both dry and wet seasons (Nnaji *et al.* 2022). *Clarias gariepinus* was

reported to contain 0.025- 0.709 mg/kg, 0.093- 0.529 mg/kg, 22.513 - 133.729 mg/kg while *Oreochromis niloticus contained* 0.118 - 2.485 mg/kg, 0.627 - 9.364 mg/kg and 69.314 - 172.014 mg/kg of cadmium, lead and iron respectively in both seasons (Nnaji *et al.* 2022). Also, the total hydrocarbon content of Urashi River ranged between 0.07 to 0.77 mg/L with Ogwuaniocha water samples having the highest values for both seasons (Nnaji *et al.* 2022). Mohamed *et al.* (2019) reported decreased activity of AST in *Tilapia zilli* and *Mugil capito.* Dawood *et al.* (2022) reported increased AST and ALT in catfish following hypersalinity stress.

Lipid profile parameters

Table 5 presents the result of the fish lipid profile. Cholesterol (CHOL) concentration of wet-season catfish was like those of dry season, ranging between 175-227.61 mg/dl while that of wet-season tilapia (323.14 mg/dl) was significantly ($p< 0.05$) higher than that of the dry-season (146.20 mg/dl). The concentration of triacylglycerides of wet season catfish was similar while that of Abacheke (183.11mg/dl) was significantly ($p< 0.05$) higher when compared to that of Ogwuaniocha catfish (71.47 mg/dl) for dry season. High-density lipoproteins (HDL-C) concentration of wet season catfish was low (43.83%) but like those of dry season (73.85 and 68.29 mg/dl) for Abacheke and Opuoma while that of Ogwuaniocha (121.74 mg/dl) was significantly ($p< 0.05$) higher. The concentration of very low-density lipoproteins (VLDL-C) of wet season tilapia (26.24 mg/dl) was significantly ($p< 0.05$) lower when compared to dry season tilapia (68.05 mg/dl). Low-density lipoproteins (LDL-C) concentrations of all the wet-season fish species were higher than those of dry-season samples. LDL-C levels of >100mg/dl and TG levels of >150mg/dL raises the risk of cardiovascular diseases. In this study, there was a non-significant ($p< 0.05$) decrease in cholesterol concentration for catfish in both seasons except Ogwuaniocha. Triacylglycerides concentration increased significantly ($p> 0.05$) in the dry season for Abacheke catfish and Opuoma tilapia. Similarly, very low-density lipoproteins (VLDL-C) fractions increased significantly ($p> 0.05$) in catfish from the wet season as well as Abacheke dry season and dry season Opuoma tilapia, showing that its concentration depends on the triglyceride fractions. High-density lipoproteins (HDL-C) of catfish in both seasons were decreased except for that of Ogwuaniocha. A non-significant ($p< 0.05$) decrease in low-density lipoproteins (LDL-C) was observed in all the fish species in the dry season. The increase in triglycerides and very low-density lipoproteins could be a consequence of the increased synthesis of lipids to counterbalance the effect of stress since large amounts of energy are needed for this process (Sayed *et al.,* 2011). The increase in triglycerides and very low-density lipoproteins corroborates that of Mohamed *et al.* (2019). Lipids are important components of cell membranes (Gurr *et al.,* 2016). They are involved in biochemical processes involving signal transduction and molecular recognition (Van Meer *et al.,* 2008). The poor lipid profile of the fish samples evidenced by unsafe triglyceride and LDL-cholesterol levels, suggests poor liver function in the fish samples.

Histopathology of gills and muscles of catfish

Photomicrographs of the gills of catfish are presented in Figure 2. The photomicrograph of Mmahu and Opuoma catfish gills had areas of marked necrosis, diffused lamellar, and depleted epithelial linings of the filaments, as well as atrophic filaments. A photomicrograph of sections of the muscles of catfish is presented in Figure 3. Ogwuaniocha muscle showed normal architecture. Mmahu, Abacheke and Opuoma fish muscles showed marked multifocal accumulations of inflammatory cells replacing the atrophic muscle fibres, cluster of atrophic muscle fibres, increased endomysial connective tissue and oedema separating the muscle fibres. Photomicrograph of sections of the liver of catfish is presented in Figure 3. Ogwuaniocha fish liver had normal architecture while the Mmahu and Opuoma had areas of mild inflammatory cellular infiltrates in the portal vein, central vein and parenchyma. Fish species (catfish and tilapia) from Mmahu, Abacheke and Opuoma in both seasons showed histopathological changes in the gill, muscle and liver tissues. Diffused marked lamellar absence, marked necrosis and depletion of epithelial cells lining the filaments of gills were observed. This result corroborated the finding of Shahida *et al.* (2020) for fish samples in polluted water. Diffused marked lamellar absence might be due to the presence of fluid between the epithelium and basement membrane. Liver tissues showed marked multifocal accumulations of inflammatory cells, a cluster of atrophic muscle fibres, increased endomysial connective tissue and oedema separating the muscle fibres. This finding is consistent with the report of Abiona *et al.* (2019) for fish exposed to heavy metal pollution. It resembles the alterations reported by El-Shebly and Elbaghdady (2011) for fish samples under oil pollution.

Conclusion

In conclusion, fish samples from the four locations along the Urashi River have poor lipid profiles, and high levels of cholesterol and triglycerides. The aspartate aminotransferase of the fish samples was very high compared to a safe level and suggested poor liver function. Therefore, the consumption of fish samples from the Urashi River may not be safe. Remediation measures should be applied to Urashi River to promote the production of fish samples with good nutrient quality.

Contribution to the field statement

This paper investigated the effect of crude oil pollution on two fish species (catfish and tilapia) harvested from four different points (Mmahu, Abacheke, Opuoma and Ogwuaniocha communities) along Urashi River in the Niger Delta region of Nigeria. The fish used for this research was harvested in the wet and dry seasons. Enzyme markers of liver damage had high values suggesting malfunctioning livers. The structure of the fish gills, liver and muscles suggested that they were

contaminated. The high low-density lipoprotein and triglyceride values also indicate pollution and contamination. There is a need to ameliorate the contamination of the Urashi River to promote aquatic life.

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Table 1: GPS coordinates of the sampling points

Location	Sample 1D	Coordinates	
		Easting	Northing
Abacheke 1	AB1	006 42″.272	05 30″.779
Abacheke 2	AB2	006 42″.379	05 30″.795
Abacheke 3	AB3	006 42″.688	05 30″.015
Mmahu 1	MM1	006 43″.843	05 33″.815
Mmahu 2	MM2	006 43″.878	05 33″.923
Mmahu 3	MM3	006 43″.908	05 33″.966
Opuoma 1	OP1	006 44″.511	05 36″.273
Opuoma 2	OP2	006 44″.565	05 36″.205
Opuoma 3	OP3	006 44″.586	05 36″.058
Ogwu-Aniocha 1	UG1	006 44″.146	05 47″.156
Ogwu-Aniocha 2	UG2	006 45″.095	05 47″.759
Ogwu-Aniocha 3	UG3	006 45″.224	05 48″.172

Source: Nnaji *et al*., 2022

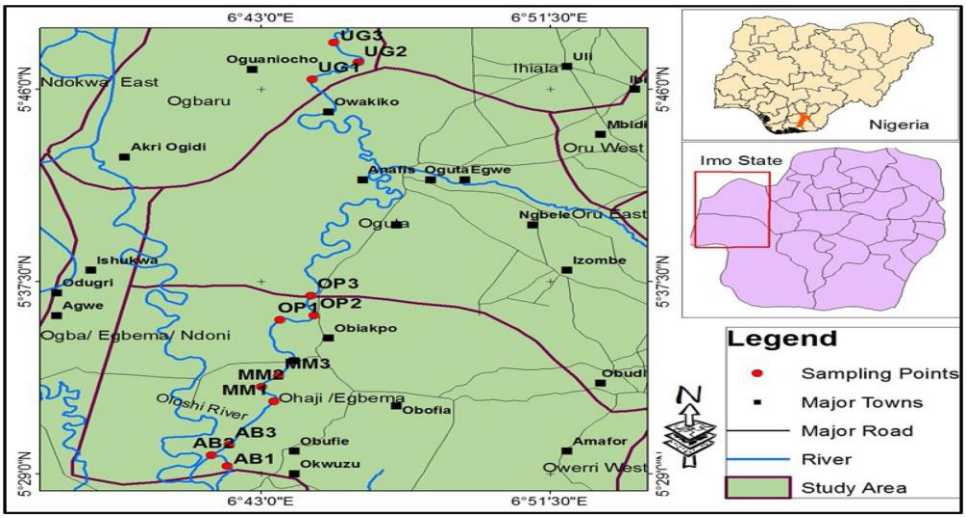

Fig. 1: Map of the study area

Table 2: Availability of fish samples during wet and dry seasons

Location	Wet season		Dry season	
	Catfish (*Clarias gariepinus*	**Tilapia (*Oreochromis niloticus***	**Catfish (*Clarias gariepinus)***	**Tilapia (*Oreochromis niloticus)***
Mmahu	Available	Available	Unavailable	Unavailable
Abacheke	Unavailable	Unavailable	Available	Unavailable
Opuoma	Unavailable	Unavailable	Available	Available
Ogwuaniocha	Unavailable	Unavailable	Available	Unavailable

Table 3: Proximate composition of fish

	Wet season		Dry season			
Parameters	**Mmahu catfish**	**Mmahu tilapia**	**Abacheke catfish**	**Opuoma catfish**	**Opuoma tilapia**	**Ogwuaniochacatfish**
MC (%)	72.62±0.01 ^{a}	53.26±0.01^{b}	73.04± 0.01^{a}	75.95± 1.03^{a}	75.55 ±0.89^{a}	53.79 ± 2.61^{b}
CP (%)	15.72 ± 0.01^{c}	19.99± 0.01^{b}	14.77± 0.01^{c}	15.20 ± 0.16^{c}	14.98± 0.28^{c}	21.25 ± 0.69^{a}
FAT (%)	1.55 ± 0.01^{ab}	1.76± 0.01^{a}	0.36 ± 0.01^{d}	0.57 ± 0.06^{cd}	0.82± 0.23^{c}	1.43 ± 0.02^{b}
CF (%)	0.04 ± 0.01^{a}	0.04±0.01^{a}	0.06±0.01 ^{a}	0.05 ± 0.01 ^{a}	0.03 ± 0.01^{a}	0.01 ± 0.06 ^{a}
ASH (%)	0.95±0.01b	1.06±0.01^{b}	1.93±0.01^{a}	1.64±0.41^{ab}	1.83± 0.35 ^{a}	1.37 ± 0.01^{ab}
CHO (%)	9.11±0.01^{bc}	23.89±0.01^{a}	9.83±0.01^{b}	6.59±0.40^{c}	6.78±0.73^{c}	22.27±1.78^{a}
EV (Kcal)	113.31±0.04^{b}	191.49±0.08^{a}	101.75±0.07^{bc}	88.91±3.11^{a}	94.53±6.09^{c}	186.97±9.71^{a}

The value with different superscripts $^{a, b, c, d}$ across the row is significant P < 0.05.
MC – Moisture content, CP – crude protein, CF – crude fibre, CHO – carbohydrate, EV –energy value.

Table 4: Fish liver function parameters

	Wet season			Dry season		
Parameters	**Mmahu catfish**	**Mmahu tilapia**	**Abacheke catfish**	**Opuoma catfish**	**Opuoma tilapia**	**Ogwuaniocha catfish**
AST (U/L)	22.20±0.72^{c}	27.60±1.74^{c}	19.43±2.24^{c}	35.05± 1.23^{c}	144.33± 2.96^{a}	123.93 ± 8.62^{b}
ALT (U/L)	9.05 ± 0.60^{b}	5.92 ± 0.48^{b}	7.77 ± 0.54^{b}	11.65± 1.22^{b}	24.77 ± 1.11^{a}	7.57 ± 1.20^{b}
ALP (U/L)	8.02 ± 0.19^{b}	11.20±0.10^{a}	6.65 ± 0.40^{b}	6.70 ± 0.56^{b}	9.03 ± 0.09^{ab}	8.32 ± 0.06^{b}
TP (g/dL)	4.23±0.33^{ab}	3.87± 0.16^{ab}	4.71 ± 0.34^{a}	3.68 ± 0.65^{ab}	2.20 ± 0.08^{b}	4.08 ± 0.12^{ab}
ALB (g/dL)	1.53± 0.12^{ab}	1.72 ± 0.05^{a}	1.18 ± 0.05^{c}	1.42 ± 0.03^{bc}	1.21 ± 0.06^{c}	1.59 ± 0.03^{ab}
GLB (g/dL)	2.70± 0.37^{ab}	2.15± 0.15^{ab}	3.53 ± 0.31^{a}	2.26 ± 0.63^{ab}	0.99 ± 0.04^{b}	2.49 ± 0.10^{ab}

Values with different superscripts $^{a, b, c, and\ d}$ across the row are significant (p < 0.05).
AST – aspartate aminotransferase, ALT – alanine aminotransferase, ALP – alkaline phosphatase, TP – total proteins, ALB – albumin, GLB – globulin

Table 5: Fish lipid profile parameters

Parameters	Wet season		Dry season			
	Mmahu catfish	Mmahu Tilapia	Abacheke catfish	Opuoma catfish	Opuoma tilapia	Ogwuaniocha catfish
CHOL (mg/dL)	206.04±24.7^{b}	323.14±28.6^{a}	175.00± 7.7^{b}	194.49± 20.2^{b}	146.20 ± 4.8^{b}	227.61 ± 7.6^{ab}
TAG (mg/dL)	94.48 ± 3.5^{d}	131.19± 5.7^{c}	183.11± 0.9^{b}	41.72 ± 6.5^{e}	340.26 ± 4.4^{a}	71.47 ± 3.4^{de}
HDL-C (mg/dL)	43.83 ± 2.1^{c}	192.35± 4.0^{a}	73.85 ± 2.6^{c}	68.29 ± 6.2^{c}	51.38± 4.2^{c}	121.74 ± 4.0^{b}
VLDL-C (mg/dL)	18.90 ± 0.71^{d}	26.24±1.1^{c}	36.62±0.2^{b}	8.34 ± 1.3^{e}	68.05 ± 0.9^{a}	14.29 ± 0.7^{de}
LDL-C (mg/dL)	143.32±26.09^{a}	104.56±33.1^{a}	64.52±5.4^{a}	117.86±23.6^{a}	26.77± 8.4^{a}	91.58 ± 5.7^{a}

Values with different superscripts $^{a, b, c, d,}$ and ^{e} across the row are significant ($p < 0.05$).
CHOL – cholesterol, TAG – triacylglycerides, HDL-C – high-density lipoproteins, VLDL-C – very low-density lipoproteins, LDL-C – low-density lipoproteins

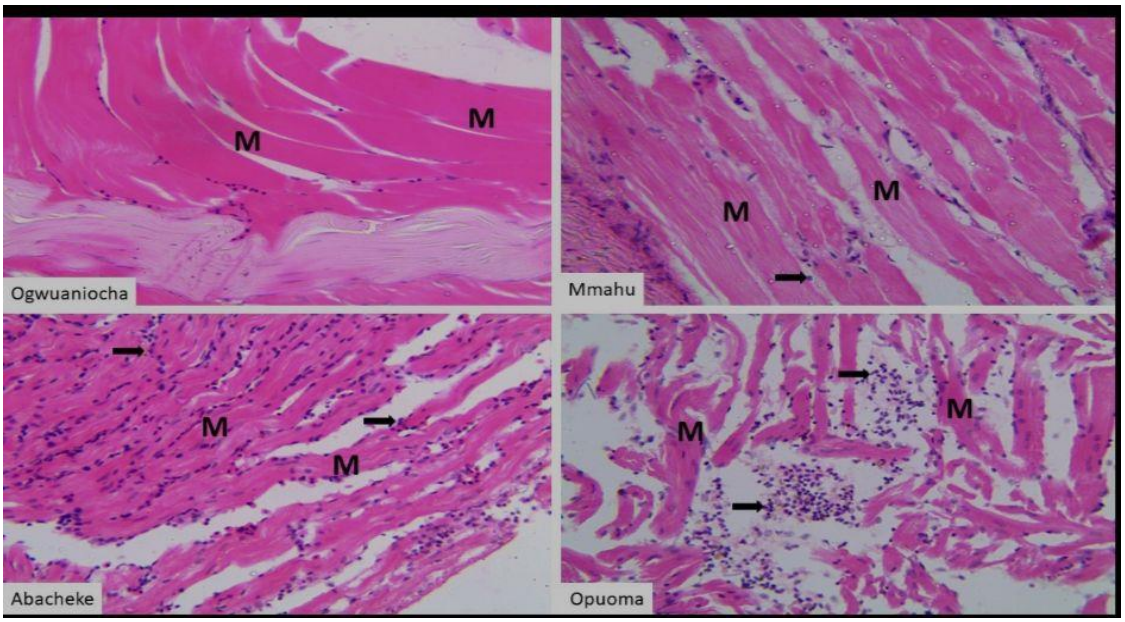

Fig. 2: Photomicrograph of sections of the muscles of catfish
The M shows the muscle fibres and the arrow shows the inflamed cells

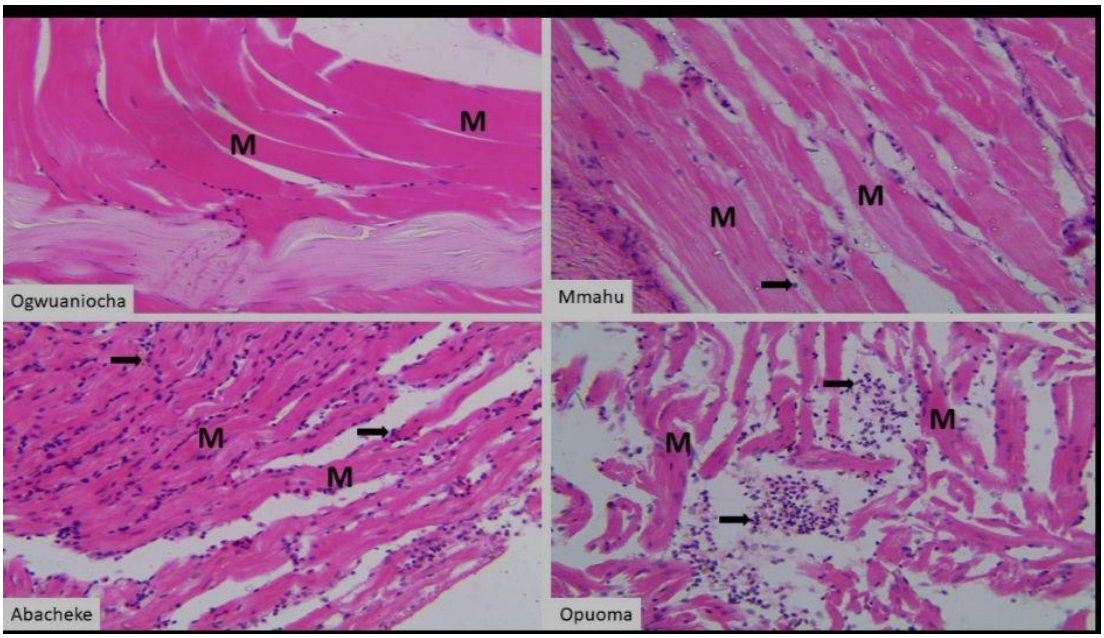

Fig. 3: Photomicrograph of sections of the liver of catfish
The CV shows the central vein and arrow points are at areas of inflammatory cell infiltrations