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Full Length Research Paper

Fatty acid profiles of the eggs and juvenile muscle of Nile perch (*Lates niloticus,* L. 1758*)* caught from Lake Victoria, Uganda

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Fatty acid profiling of the eggs and muscle of *L. niloticus* juveniles was carried out, revealing the presence of two types of cholesterol and over twenty fatty acids. The total saturated fatty acid, total monounsaturated acid and the total polyunsaturated fatty acid compositions in the various samples lay in the ranges 13.39 to 41.81, 19.41 to 42.98 and 22.17 to 43.63%, respectively. There was a detection of an abundance of palmitic, stearic, oleic and docosahexaenoic fatty acids in all the samples investigated. The n-3/n-6 ratio averaged at 5.12±4.28. Cholesterol was detected in all the samples except in the eggs. This information is necessary as an aid to the formulation of an entire feed process required for the rapid replenishing of the declining *L. niloticus* stocks in Lake Victoria.

Key words: *Lates niloticus,* muscle tissue, fatty acids, Lake Victoria, cholesterol.

INTRODUCTION

Nile perch (*Lates niloticus*) are commonly found in the waters of the River Nile and in the lakes and other rivers in eastern, central and western Africa (Hopson, 1972). The fish species gained its popularity as a source of protein in East Africa in the late 1970's, some twenty years after its first introduction in the waters of the Lakes Victoria, Nabugabo and Kyoga (Ogutu-Ohwayo, 1985; Bwanika et al., 2006). Currently, Nile perch is a highly demanded East African fish export commodity (Okedi, 2005), exerting undue pressure on the fisheries industry and resulting in a marked decrease in Nile perch populations in the respective water bodies (LVFO, 2009). The rather rapid decline in Nile perch populations in East Africa and in the waters of Lake Victoria in particular over the recent past, has precipitated major concerns regarding the urgent need to put in place technologies geared towards the restoration of the Nile perch populations (Munyaho, 2004). Unlike many of the other fish species commonly found in the Great Lakes region, the Nile perch is largely fatty, so much so that local fishermen used to fry it all by itself and collect its oil for further domestic use. *L. niloticus* is known to be rich in highly unsaturated and polyunsaturated fatty acids (Ogwok et al., 2008), which renders the species an important source of these fatty acids. Fatty acid profile data in other fishes, plants and animal tissues is mentioned elsewhere in current literature (Turon et al., 2005; Ugoala et al., 2009; Tang et al., 2009). Research findings indicate that one of the avenues through which Nile perch could possibly be sustainably conserved is through aquaculture (Gregory, 2006), and that this could go well alongside developing an artificial fish feed for this species. In this respect, studies indicate a close relationship between body composition and the dietary fatty acid requirements in fish (Mourente and Tocher, 1992a).

Fish require fat as a source of energy and also as a source of fatty acids that are important ingredients in growth and reproduction (Sargent et al., 1995). The level of fat within the body of a fish highly depends on its dietary levels as well as on the different stages in the life-cycle of the fish (Uotani et al., 1990). Fatty acids usually comprise a chain of carbon atoms with a carboxyl group

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at one end and a methyl group at the other end. In saturated fatty acids, each carbon atom in the molecular chain forms single bonds with four other atoms. If a carbon is not bound to four other atoms, double or triple bonds are formed. Consequently, fatty acids are normally categorised based on molecular chain length, the existence of multiple bonds and the spatial arrangement of hydrogen atoms in these bonds (Abbas et al., 2009). Fatty acids are important for fish growth, reproduction and movement, as well as being a major source of energy (Tocher, 2003). Fish adopt various nutritional requirements at their different stages of development (Tang et al., 2009). It has, for example, been observed in *L. niloticus* (Hopson, 1972) that 0.30 to 0.35 cm larvae tend to feed on *Cladocera* and *Copepod nauplii*, whereas those between 0.35 and 1.00 cm feed primarily on *Copepods* and insect nymphs. Consequently, during the culturing of *L. niloticus* it becomes of vital importance to provide feeds with the appropriate fatty acid inclusions at the larval (Tang et al., 2009), juvenile (Mourente, 2003) and broodstock stages (Sorbera et al., 2001), so as to offset possible nutritional deficiencies and to increase the chances of larval survival (Rimmer and Reed, 1989).

The purpose of the present study therefore was to establish the fatty acid profiles of the eggs as well as of the muscles of *L. niloticus* at various stages of growth. This knowledge would subsequently be used to provide vital information on the fatty acid dietary requirements for *L. niloticus* at its various stages of development, and as an aid in the feed formulation process. This may be important during the culture of *L. niloticus*, which is an avenue for the rapid replenishing of *L. niloticus* stocks in Lake Victoria.

MATERIALS AND METHODS

Sample collection and analysis

Twelve fish of various sizes were caught from Lake Victoria at Kiggungu landing site (Longitude 36° 26′ 15″E, Latitude 00° 02′ 49″N) using 3" beach seine and 7 mm mosquito nets. The samples were divided into four groups according to the total length: 0 to 10, 11 to 20, 21 to 30 and 31 to 40 cm, with each group comprising three members. The fish were immediately transported in ice-cooled boxes to the Department of Chemistry, Makerere University, for laboratory analysis. The eggs were collected from three sexually mature females (92.5 to 97.0 cm total length). Muscular portions from the caudal and abdominal areas were sliced off the fish using a sharp clean stainless-steel knife. The eggs, egg fat and muscle were separately homogenised using a blender and stored at –86°C for 12 h, before further analysis. In each case, the analyses were carried out in triplicate.

Esterification of the fatty acids

Dry hydrogen chloride gas was bubbled through anhydrous methanol (HPLC grade) in a flask immersed in an ice-bath and its concentration periodically monitored by the increase in mass of the methanol. The gas was turned off when the methanol reached 2M in HCl. Sub-samples of the fish eggs, egg-fat and muscle tissue (weighing approximately 30 to 50 mg) were transferred to thick-walled glass tubes. 1 ml of the acidified anhydrous methanol was added. Nitrogen gas was flushed through the tubes which were then securely sealed with Teflon-lined screw caps and left for a period of 2 h in an oven thermostated at 90°C. The samples were subsequently methanolysed and all the fatty acids in the samples were converted to their methyl esters in the methanolic solution (Grahl-Nielsen and Barnung, 1985).

Extraction of the fatty acid methyl esters

After cooling to room temperature, half the methanol was allowed to evaporate by bubbling nitrogen gas, with 0.5 ml distilled water being added to reduce the solubility of the esters. Extraction of the product from the methanol-water phase was effected using two successive 1.0 ml aliquots of HPLC grade n-hexane and centrifuged at 1500 rpm for 3 min. The methyl esters were obtained from the upper organic layer by siphoning and stored under refrigeration for subsequent gas chromatograph/mass spectrometry (GC/MS) analysis using an Agilent 6890N GC–MS (USA version) spectrometer.

GC/MS analysis of the methyl fatty acid esters

1 µl of the mixed hexane extracts was injected onto a 25 by 0.25 mm fused silica column with polyethylene-glycol (PEG) as the stationary phase with a 0.2 µm thickness (CP-WAX 52CB Chrompack) and helium gas at 20 psi as the mobile phase. The column was mounted in a GC/MS (Agilent 6890N). The column was mounted in a GC/MS (Agilent 6890N with autosampler 7683B series, fitted with an electronic pressure control and mass selective detection (ionisating energy, 70 eV; source temperature, 250°C)). The injector temperature was 260°C. The temperature of the column was kept at 90°C for 4 min after injection and thereafter increased to 165°C at a rate of 30°C/min, followed by an increase of 3°C/min to 225°C. The temperature was then maintained at 225°C for close to 11 min. The fatty acids in the samples were identified by means of the standard mixture GLC-68D from Nu-Chek-Prep (Elysian, Minn., USA) containing 20 fatty acids and by mass spectrometry. Quantification of the esters was achieved by integration of the peaks using Chemstation software obtained from Thermo LabSystems, with the relative amount of each fatty acid ester in each sample being expressed as a percentage of all the esters in the sample.

Statistical analysis

The results obtained from the chromatography readings were presented as means ±SD. The data was analysed using one-way ANOVA and the correlations were performed using GraphPad.Prism.v5.01 Statistical software.

RESULTS

A total of twenty-seven different fatty acids along with two cholesterol isomers were detected from the eggs, egg fat and muscle tissue (Tables 1, 2 and 3). The total saturated fatty acid composition ranged from 13.39±2.45 to 40.81±0.46%, that of the monounsaturated acids from

Table 1. Fatty acid content (expressed as percentage of total fatty acids) in the eggs and fat tissue around the eggs of *L. niloticus*.

	F/A mean percentages	
Fatty acids	**Egg fat N = 3**	**Egg N = 3**
12:0	0.16±0.00	0.02±0.00
14:0	4.45±0.26	1.20±0.25
15:0	0.49±0.00	0.10±0.03
16:0	23.43±0.54	8.37±1.60
17:0	1.49±0.04	0.31±0.05
18:0	10.16±0.30	3.39±0.51
Total saturated fatty acids	**40.18±0.46**	**13.39±2.45**
14:ln5	0.13±0.00	0.05±0.00
iso 15:00	0.68±0.00	0.27±0.06
16:ln7	7.34±0.21	6.26±1.22
iso 17:00	0.72±0.05	0.47±0.01
α 1so 17:00	0.26±0.03	0.11±0.02
17:1n9	1.09±0.04	0.93±0.14
18:1n9	21.82±0.53	31.12±9.28
18:1n7	4.96±0.11	3.53±1.13
20:1n9	0.64±0.02	0.24±0.04
Total monounsaturated fatty acids	**37.64±0.35**	**42.98±11.87**
18:2n6	4.76±0.26	2.15±3.04
18:2n4	0.54±0.04	14.05±19.21
18:3n6	0.22±0.01	2.07±2.09
18:3n3	4.92±0.18	7.18±1.09
20:3n6	0.53±0.04	1.02±0.15
20:4n6	1.64±0.06	2.66±0.40
20:5n3 (EPA)	1.07±0.05	1.04±0.16
21:5n3	0.23±0.01	0.00±0.00
22.4n6	0.59±0.03	0.48±0.00
22:5n6	0.49±0.01	0.95±0.13
22:5n3	3.04±0.07	3.09±0.44
22:6n3 (DHA)	4.13±0.07	8.95±1.57
DHA/EPA	3.86	7.38
Total polyunsaturated fatty acids	**22.16±0.81**	**43.64±14.32**
C1	N.D	N.D
C2	N.D	N.D
Total cholesterol	**0.00**	0.00
(n - 3) total	13.39	20.26
(n - 6) total	8.23	9.33
n-3/n-6	**1.63**	**2.17**

N.D: Not detected.

18.73±0.25 to 42.98±11.87%, while that of the polyunsaturated fatty acids lay between 22.16±0.81 and 43.64±14.32%. Of the saturated acids, the most abundant was palmitic acid (C16:0) occurring in the egg fat, 21 to 30 cm of the abdominal muscle and 31 to 40 cm of the caudal muscle (23.43±0.54, 24.53±0.01 and 23.75±0.86%, respectively). Among the monounsaturated acids, it was oleic acid (18:1n9) that was the most abundant (Tables 2 and 3). Of the polyunsaturated fatty acids, docosahexaenoic (C22:6n3) was the most available. The analysis also indicated that 16:0, 18:0, 16:1n7, 18:1n9, 18:1n7, 18:3n3, 18:2n6, 20:4n6, 20:5n3, 22:5n3 and 22:6n3 (Figure 1) were the most abundant fatty acids in the eggs and all the other portions of the

Table 2. Fatty acid content (expressed as percentage of total fatty acids) in the abdominal muscle of *L. niloticus*.

Abdominal	Fish size classes (cm)			
	0-10	11-20	21-30	31-40
Fatty acids	**N = 3**	**N = 3**	**N = 3**	**N = 3**
12:0	0.15±0.04	0.18±0.02	0.13±0.00	0.25±0.00
14:0	1.83±0.21	1.48±0.59	1.81±0.23	3.79±0.31
15:0	0.83±0.51	0.67±0.30	0.40±0.08	0.46±0.03
16:0	21.90±0.01	21.21±0.91	24.53±0.01	22.83±2.12
17:0	2.15±0.06	2.24±0.14	1.76±0.31	1.35±0.09
18:0	10.86±0.56	12.98±2.99	13.17±0.87	9.28±0.95
Total saturated fatty acids	**37.72±0.45**	**38.76±1.34**	**41.80±0.88**	**37.96±3.52**
14:ln5	0.13±0.07	0.15±0.01	0.18±0.01	0.32±0.00
iso 15:00	0.62±0.78	0.47±0.21	0.39±0.07	0.29±0.00
16:ln7	7.14±0.25	5.59±3.57	4.12±1.23	7.59±0.20
iso 17:00	0.83±0.31	0.77±0.25	0.63±0.09	0.90±0.02
α 1so 17:00	0.79±0.02	0.77±0.11	0.45±0.02	0.45±0.01
17:1n9	1.43±0.02	1.43±0.28	0.87±0.02	0.96±0.07
18:1n9	9.67±0.15	9.24±0.70	12.05±1.48	15.73±1.21
18:1n7	6.12±0.03	5.30±1.44	5.15±0.06	5.24±0.43
20:1n9	0.57±0.14	0.69±0.06	0.00±0.00	0.50±0.03
Total monounsaturated fatty acids	**27.30±0.04**	**24.41±6.47**	**23.84±2.92**	**31.98±1.94**
18:2n6	1.7±0.02	1.24±0.51	2.97±0.25	3.83±0.20
18:2n4	1.86±0.46	1.30±1.54	0.00±0.00	0.43±0.31
18:3n6	0.45±0.78	0.44±0.20	0.00±0.00	5.49±7.49
18:3n3	2.10±0.27	1.36±1.07	2.63±0.46	4.64±0.24
20:3n6	1.05±1.04	1.26±0.12	0.32±0.01	0.00±0.96
20:4n6	5.91±0.49	7.32±1.71	6.87±0.68	3.24±0.27
20:5n3 (EPA)	4.95±1.05	3.89±1.99	0.77±0.03	1.66±0.18
21:5n3	0.95±0.14	1.37±0.51	0.56±0.02	0.25±0.02
22.4n6	0.85±0.59	1.44±0.86	0.97±0.04	0.52±0.03
22:5n6	1.16±1.07	2.24±1.29	1.05±0.04	0.40±0.06
22:5n3	3.97±0.37	3.65±0.20	3.80±0.83	3.17±0.09
22:6n3 (DHA)	7.41±0.47	7.36±0.87	12.26±1.46	5.64±0.75
DHA/EPA	1.50	1.89	15.92	3.40
Total polyunsaturated fatty acids	**32.36±0.08**	**32.87±2.32**	**32.20±2.13**	**29.27±5.50**
C1	0.49±0.24	1.12±0.76	0.66±0.02	0.28±0.02
C2	2.13±0.38	0.00	1.49±0.05	0.54±0.03
Total cholesterol	**2.62±0.25**	**1.12**	**2.15**	**0.82**
(n - 3) total	19.38	17.63	20.02	15.36
(n - 6) total	11.12	13.94	12.18	13.48
n-3/n-6	**1.74**	**1.26**	**1.64**	**1.14**

L. niloticus analysed. Further results from the investigations indicated that all the portions of *L. niloticus* contained high quantities of 16:0, 18:0, 16:1n7, 18:1n9, 18:1n7, 18:3n3, 18:2n6, 20:4n6, 20:5n3, 22:5n3 and 22:6n3 (Figure 1). There were, however, variations; for example, the abundance of 16:0 increased with fish length. On the other hand, the abundance of 16:1n7, 18:1n9, 18:2n6 and 18:3n3 in the eggs was higher than that in fish of 0 to

Table 3. Fatty acid content (expressed as percentage of total fatty acids) in the caudal muscle of *L. niloticus*.

Caudal	Fish size classes (cm)			
	0-10	11-20	21-30	31-40
Fatty acid	**N=3**	**N=3**	**N=3**	**N=3**
12:0	0.00±0.00	0.00±0.00	0.00±0.00	0.25±0.14
14:0	0.91±0.03	0.97±0.03	0.76±0.13	3.10±0.73
15:0	0.50±0.07	0.49±0.02	0.32±0.56	0.39±0.03
16:0	19.29±0.77	22.2±0.10	21.54±0.89	23.75±0.86
17:0	1.85±0.09	2.04±0.05	1.15±1.89	1.03±0.01
18:0	13.02±0.08	11.47±0.11	12.12±0.79	9.35±0.58
Total saturated fatty acids	**35.57±0.72**	**37.17±0.27**	**35.89±0.35**	**37.87±1.19**
14:ln5	0.00±0.00	0.09±0.00	0.00±0.00	0.16±0.01
iso 15:00	0.27±0.00	0.51±0.02	0.32±0.47	0.27±0.11
16:ln7	3.32±0.14	4.77±0.22	2.44±1.47	7.43±1.69
iso 17:00	0.75±0.08	0.67±0.02	0.57±0.29	0.82±0.14
α 1so 17:00	0.61±0.01	0.53±0.21	0.44±0.71	0.45±0.05
17:1n9	1.00±0.04	1.25±0.44	0.84±0.83	0.85±0.06
18:1n9	8.16±0.83	8.80±0.58	8.62±0.96	12.86±0.58
18:1n7	4.75±0.88	6.36±0.30	4.66±1.89	5.39±0.20
20:1n9	0.55±0.03	0.75±0.03	0.84±0.19	1.77±0.09
Total monounsaturated fatty acids	**19.41±0.36**	**23.73±1.22**	**18.73±0.25**	**30.00±2.95**
18:2n6	1.37±0.26	1.67±0.05	2.27±0.15	2.72±0.17
18:2n4	2.33±0.13	0.00±0.00	2.24±0.16	1.94±0.10
18:3n6	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
18:3n3	1.13±0.03	1.60±0.30	1.50±1.47	3.44±0.26
20:3n6	0.96±0.79	1.53±0.05	1.20±0.68	1.72±0.09
20:4n6	6.62±0.06	7.12±0.04	8.66±1.74	4.91±1.78
20:5n3 (EPA)	2.97±0.80	6.18±0.86	2.92±1.79	1.88±0.53
21:5n3	0.00±0.00	0.97±0.03	0.62±1.69	0.00±0.00
22.4n6	0.88±0.05	0.54±0.02	1.02±0.59	1.05±0.05
22:5n6	1.83±0.69	1.41±0.05	1.92±0.48	0.75±0.04
22:5n3	3.49±0.68	5.48±0.21	4.31±0.39	4.29±0.21
22:6n3 (DHA)	19.41±1.75	10.29±0.43	15.23±1.69	7.47±2.40
DHA/EPA	6.54	1.67	5.22	3.97
Total polyunsaturated fatty acids	**40.99±1.78**	**36.79±1.04**	**41.89±0.25**	**30.17±4.21**
C1	1.15±0.60	0.69±0.02	1.02±0.49	0.59±0.03
C2	2.88±0.82	1.59±0.06	2.58±1.59	1.37±0.07
Total cholesterol	**4.03±1.22**	**2.28±0.64**	**3.60±1.10**	**1.96±0.55**
(n - 3) total	27.00	20.46	24.58	17.08
(n - 6) total	11.66	9.41	15.07	11.15
n-3/n-6	**2.32**	**2.17**	**1.63**	**1.53**

40 cm total length. Table 1 also shows that cholesterol isomers were detected in the abdominal and caudal muscles but not in the eggs or the egg fat.

Statistical analysis indicated that there was a significant correlation (r^2 = 0.715, $p<0.0001$, 2-tailed, α = 0.05), between the composition of fatty acids in the eggs and in the egg fat. There was however little variance ($p<0.05$) between the mean fatty acid percentage in the various

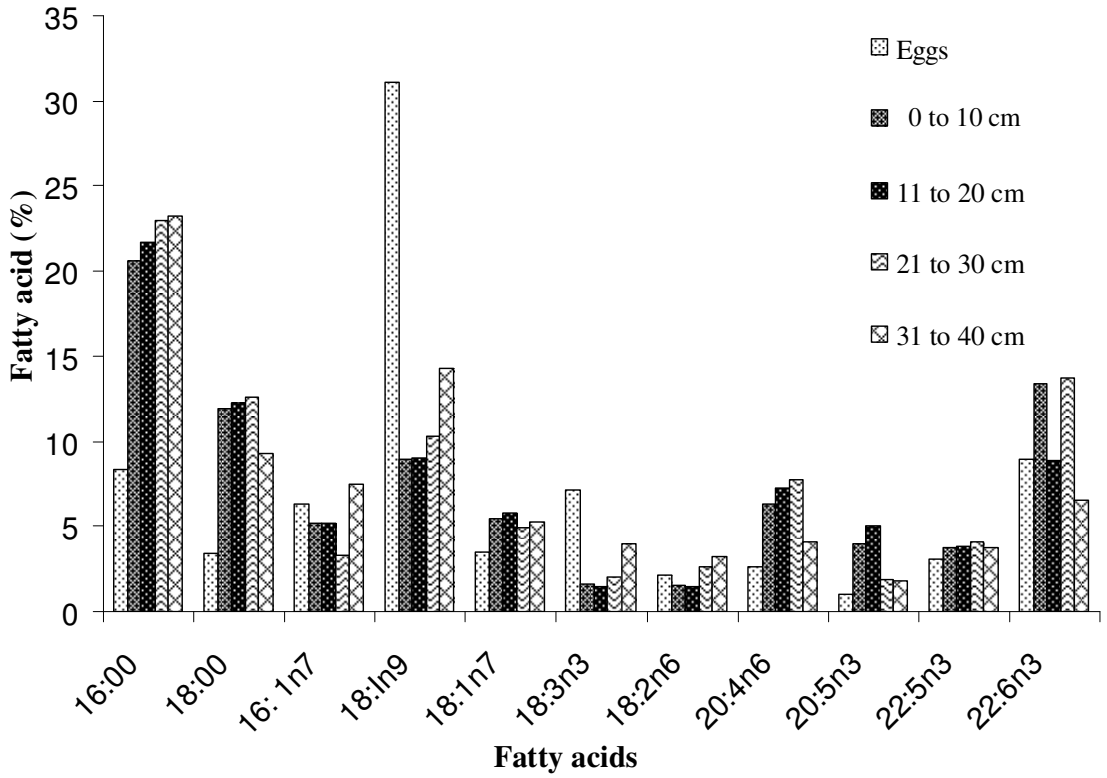

Figure 1. Abundance of fatty acids in the *L. niloticus* eggs and fish of 0 to 40 cm (TL).

class sizes of the abdominal and caudal muscles.

DISCUSSION

Fatty acid composition in animals depends on a number of factors such as sex, age, size and body temperature. As temperature decreases, the level of unsaturation tends to increase for fish so as to maintain membrane fluidity and general body flexibility. When the surrounding temperatures increase, an increase of phospholipids is necessary to counter excessive fluidity (Eastman, 1990; Martino and Cruz, 2004). This phenomenon seems to work well in fish species that experience extreme weather conditions especially in bitterly cold winters and very hot summers. This was not observed in *L. niloticus* where the concentration of polyunsaturated fatty acids (22.16±0.81 to 43.64±14.32%), monounsaturated fatty acids (18.73±0.25 to 42.98±11.8%) and saturated fatty acids (13.39±2.45% to 40.18±0.48%) is almost similar, owing to the species being a tropical fish that does not experience such extreme climatic conditions. Age impacts significantly on the variation of fatty acid dietary requirements in fish (Izquierdo and Fernandez-Palacios, 1997; Kolkovski, 2005). Fish exhibit a variety of food intake at their different stages of development. In this respect, *L. niloticus* feeds on zooplankton (*Cladocera*) at 0.30 cm length before changing to insect larvae and eventually to a fish diet (haplochromines, tilapianes, Barbus, among others) on attaining a total length of 2.0 cm (Hopson, 1972). This could explain why *L. niloticus* juveniles tend to be restricted around shallow vegetated areas were most zooplankton is found (Ogutu-Ohwayo, 1985). Much as the mouth gape determines the size of the prey that can be swallowed whole by a predator (De Silva and Anderson, 1995; Lovell, 1998; Halver and Hardy, 2002), *L. niloticus* rapidly moves up the trophic level presumably due to the need to satisfy the various fatty acid requirements at different growth stages.

In consonance, there was significant difference ($p<0.005$) between the mean fatty acid percentage in the eggs and at the 0 to 10 cm length stage. Figure 1 shows that the fatty acids: 16:0, 18:0, 16:1n7, 18:1n9, 18:1n7, 18:3n3, 18:2n6, 20:4n6, 20:5n3, 22:5n3 and 22:6n3 are particularly abundant in *L. niloticus* of 0 to 40 cm length, which is indicative of these acids possibly being required in the constitution of the eggs, larvae and juveniles (Izquierdo et al., 2001). The abundances of the fatty acids 16:1n7, 18:1n9, 18:2n6 and 18:3n3 in the eggs is high compared to that in the 0 to 40 cm fish, implying a particular necessity for these acids in the eggs of *L. niloticus*. Docosahexaenoic (22:6n3), palmitic (16:0), eicosapentaenoic (20:5n3) and oleic (18:1n9) acids have been found to be of particular importance in the egg

constitution of halibut (*Hippoglossus hippoglossus*), turbot (*Scophthalmus maximus*), plaice (*Pleuronectes platessa*), dolphin (*Coryphena hyppurus*), red sea bream (*Pagrus major*) and gilthead seabream (*Sparus aurata*) (Izquierdo et al., 2001). Investigations performed by Ugoala et al. (2009) indicate that fatty acids: 16:0, 18:0, 18:1n9, 18:1n7, 18:3n3, 20:4n6 and 20:5n3 were similarly important in *L. niloticus* from Kainji Lake dam site in Nigeria; however, the fatty acids 16:1n7, 18:2n-6, 22:5n3 and 22:6n3 were not detected. This could imply that fatty acid requirements are greatly affected by the surrounding environment, given that Kainji Lake dam site is located farther away from the equator compared to Lake Victoria. Similar changes in fatty acid composition have been observed in *Oreochromis niloticus* and *Clarias gariepinus* (Ugoala et al., 2008), probably because of the more vigorous carnivorous nature of the latter compared to that of the former.

Docosahexaenoic acid has also been found to accumulate in the larval and juvenile fish stages of *Sparus aurata*, *Clupea harengus* and *Scophthalmus maximus* (Mourente, 2003). It has been suggested that these fatty acids are of vital importance to the further development of the embryos and larvae of the common snook (Yanes-Roca et al*.,* 2009). This could explain the critical concentrations of these fatty acids in the Nile perch eggs (Docosahexaenoic: 8.95±1.57%, palmitic: 8.37%±8.37, eicosapentaenoic: 1.04±0.16% and oleic: 3.53±1.13%). This observation points to the fact that any artificial feed formulated for purposes of viable Nile perch broodstock and larval development should contain these fatty acids in this range of composition. Similar studies carried out on fatty acid profiles of fish (Izquierdo et al., 2003; Tocher and Dick, 2004; Osman et al., 2007; Ugoala, 2008; Ugoala et al., 2009) indicate that fatty acids are vital in several metabolic activities. Eicosapentaenoic, docosahexaenoic and arachidonic acids are essential for growth, development and survival (Sargent et al*.,* 1999). Eicosapentaenoic and docosahexaenoic acids in particular are heavily involved in the development of the nervous system, including the brain and visual cells (Furuita et al., 1998; Cahu et al., 2003). This could be responsible for the relatively high levels of docosahexaenoic (8.95±1.57% in the eggs and 7.41±0.47% in 0 to 10 cm juveniles) in *L. niloticus* because the species needs this fatty acid for visual development, owing to *L. niloticus* being a vigilant visual feeder (Hamba, 2002). Eicosapentaenoic and docosahexaenoic acids also improve vitality and stress resistance (Watanabe and Kiron, 1994), so that the dietary inclusion of these acids in the levels observed in the eggs (1.04±0.16% and 8.95±1.57%, respectively) and larvae (4.97±1.05% and 7.41±0.47%, respectively) will probably be of great significance for the survival and visual development of Nile perch larvae.

On the other hand, arachidonic acid is important for improving maturation and spawning quality (Sorbera et al., 2001). Docosahexaenoic is also necessary for reproduction, survival and disease prevention (Izquierdo, 2000). The high docosahexaenoic/eicosapentaenoic ratios in the *L. niloticus* eggs and egg fat (7.38 and 3.86, respectively) could be used to account for the need of this fatty acid for egg and post-hatching development. Due to their importance in fish development, the three polyunsaturated fatty acids: docosahexaenoic, eicosapentaenoic and arachidonic are considered essential for freshwater species (Yu and Sinhuber, 1975). Inadequate supply of these essential fatty acids in the diet gives rise to poor feeding and swimming activities, poor growth, fatty liver, hydops (increased water content of the muscle), shock syndrome, fin erosion, mitochondrial swelling, haemoglobin deficiency, swim bladder inflation, abnormal pigmentation, disaggregation of gill epithelia, immune deficiency and raised cortisol levels (Izquierdo, 1997). Inappropriate quantities of essential fatty acids in broodstock diets also lead to reduced fecundity and fertilisation rates, embryo deformity and damaged larval quality (Izquierdo et al., 2001). It would therefore be essential to include these critical quantities of the essential fatty acids in artificial *L. niloticus* larval and broodstock diets. One major difference is observed between the essential fatty acid requirements of fresh and those of marine-water fish (Ugoala et al., 2008); the former require either linoleic acid (18:2n-6) or linolenic acid (18:3n3) or both, while for the latter the highly unsaturated fatty acids: eicosapentaenoic (20:5n3) and/or docosahexaenoic (22:6n3) are necessary (Sargent et al., 1999). Several authors (Ackman et al., 2002; Tocher, 2003; González et al., 2006) have suggested that fresh-water fish contain high concentrations of 20:4n6 and 18:2n6 fatty acids, as compared to their marine counterparts. This may be attributed to the diet of some fresh-water fish which includes algae, insects and insect larvae. Unlike other herbivorous fresh-water fishes, the diet of *L. niloticus* comprises mainly tilapines and haplochromines that in turn depend on freshwater algae (Fraser et al., 1989).

These algae are rich in linoleic and linolenic acids which are responsible for the remarkably high levels of 20:4n6 fatty acids; this ties up very well with the substantial amounts of the fatty acid 20:4n6 found in *L. niloticus* in this work. Fresh-water fish fatty acids exhibit the rather unusual ability to elongate their carbon chains through enzymatic desaturation (Steffens, 1997). This observation is contrary to what is observed in the fatty acids found in other strictly carnivorous fish species (Gutierrez and Da Silva, 1993; Jobling, 2004; Halilo, 2004). Fatty acids are indispensable in the fish diet because of their numerous functions in the metabolism and functioning of the body; yet, owing to their restricted mobility, farmed fish can only access such fatty acids through the feeds provided. It is therefore important that

fish feed formulators make appropriate fatty acid inclusions in the fish diets so that the fish can attain optimal growth potential without fatty-acid related deficiencies.

Conclusion

The presence of twenty-seven different fatty acids have been confirmed in *L. niloticus*, most of which have been attributed to the species being a tropical fish that does not experience extreme climatic conditions. Docosahexaenoic acid content in *L. niloticus* is relatively high possibly due to this fatty acid being of vital importance in young fish. It would consequently be necessary in any subsequent formulation of feeds for cultured *L. niloticus* to take into consideration the inclusion of 16:0, 18:0, 16:1n7, 18:1n9, 18:1n7, 18:3n3, 18:2n6, 20:4n6, 20:5n3, 22:5n3 and 22:6n3 fatty acids in the broodstock, larval and juvenile diet.

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REFERENCES

Abbas KA, Mohamed A, Jamilah B (2009). Fatty acids in fish and beef and their nutritional values: A review. WFL Publisher Science and Technology. J. Food Agric. Environ., 7: 3-4.

Ackman RG, McLeod C, Rakshit S, Misra KK (2002). Lipids and fatty acids of five freshwater food fishes of India. J. Food Lipids, 9: 127-145.

Bwanika GN, Chapman LJ, Kizito Y, Balirwa J (2006). Cascading effects of introduced Nile perch (*Lates niloticus*) on the foraging ecology of Nile tilapia (*Oreochromis niloticus*). Ecol. Freshwater Fish, 15: 470-481.

Cahu C, Zambonino JI, Takeuchi T (2003). Nutritional components affecting skeletal development in fish larvae. Aquaculture, 227: 254-258.

De Silva SS, Anderson TA (1995). Fish nutrition in aquaculture. Chapman and Hall Aquaculture series, London.

Eastman JT (1990). The biology and physiological ecology of notothenioid fishes. In Gon O and Heemstra PC (eds.,) Fishes of Sothern Ocean. JLB Smith Institute of Ichthyology. Grahamstown, pp. 34-51.

Fraser AJ, Sargent JR, Gamble JC, Seaton DD (1989). Formation and transformation of fatty acids in an enclosed marine food chain comprising phytoplankton, zooplankton and herring (*Clupea harengus* L) larvae. Mar. Chem., 27: 1-18.

Furuita H, Takeuchi T, Uematsu K (1998). Effects of eicosapentaenoic and docosahexaenoic acids on growth, survival and brain development of larval Japanes flounder (*Paralichtys olivaceus*). Aquaculture, 161: 269-279.

González S, Flick GJ, O'Keefe SF, Duncan SE, McLean E, Craig SR (2006). Composition of farmed and wild yellow perch (*Perca flavescens*). J. Food Compos. Anal., 19: 720–726.

Grahl-Nielsen O, Barnung T (1985). Variations in the fatty acid profile of marine animals caused by environmental and developmental changes. Mar. Environ. Res., 17: 218-221.

Gregory RG (2006). The Nile perch lates niloticus: a potential candidate for cage aquaculture. In M. Halwart JF (eds). FAO Regional Technical Expert Workshop on cage culture in Africa. Entebbe Uganda, 20-23 October 2004. FAO Fish. Proc. Rome, FAO. 6: 11.

Gutierrez LE, da Silva RCM (1993). Fatty acid composition of commercial fish from Brazil. Sci. Agric. Piracicaba, 50: 478-483.

Halilo HL, Bayır A, Sirkecio AN, Mevlüt NA, Atamanalp M (2004). Comparison of fatty acid composition in some tissues of rainbow trout (*Oncorhynchus mykiss*) living in seawater and freshwater. Food Chem., 86: 55-59.

Halver J, Hardy RW (2002). Fish nutrition. Academic Press, London, p. 824.

Hamba S (2002). Observations from initial attempts to culture Nile perch. Diploma project report. Fisheries Training Institute. Entebbe, Uganda.

Hopson AJ (1972). The study of the Nile perch (*Lates niloticus*) (Pisces: Centropomidae) in Lake Chad. Overseas Research Publication, Commonwealth Office, Overseas Development Administration, Her Majesty's Stationery Office, 19: 93.

Izquierdo M (2000). Essential fatty acid requirements in Mediterranean fish species. Cahiers Options Méditerranéennes, 63: 91-102.

Izquierdo M, Fernandez-Palacios H, Tacon AGJ (2001). Effect of broodstock nutrition on reproductive performance of fish. Aquaculture, 197: 25-42.

Izquierdo M, Fernandez-Palacios H (1997). Nutritional requirements of marine fish larvae and broodstock. In Tacon A, Basurco B, eds. Feeding Tomorrow's Fish, pp. 243-264.

Izquierdo M, Obach A, Arantzamendi L, Montero D, Robaina L, Rosenlund G (2003). Dietary lipid sources for seabream and seabass: Growth performance, tissue composition and flesh quality. Aquacult. Nutr., 9: 397.

Jobling M (2004). 'Finishing'feeds for carnivorous fish and fatty acid dilution model. Aquacult. Res., 35: 706-709.

Kolkovski S (2005). Progress in fish larval nutrition live feed enrichment and brood stock additives - Tailor made to requirements. Aqua Feeds: Formulation Beyond, 2: 7-8.

Lake Victoria Fisheries Organization (LVFO) (2009). Nile perch Market Report, 2009.

Lovell RT (1998). Nutrition and feeding of fishes. Chapman and Hall, New York.

Martino RC, Cruz GM (2004). Proximate composition and fatty acid content of the mangrove oyster *Crassostrea rhizophorae* along the year seasons. Braz. Arch. Biol. Techn., 47: 955-960.

Mourente G (2003). Accumulation of DHA (docosahexaenoic acid; 22:6n-3) in larval and juvenile fish brain. In the Big Fish Bang. Proceedings on the 26th Annual Larval Fish conference, (Eds) Howard J, Brownman and Anne Berit. Institute of Marine Research, Norway.

Mourente G, Tocher DR (1992a). Lipid class and fatty acid composition of brain lipids from Atlantic herring (*Clupea harengus,* L) at different stages of development. Mar. Biol., 112: 553-558.

Ogutu–Ohwayo R (1985). The effects of predation by Nile perch introduced in Lake Kyoga in relation to the fisheries of Lake Kyoga and Victoria. FAO Fish. Rep., 355: 18-41.

Ogwok P, Muyonga JH, Sserunjogi ML (2008). Fatty acid profile and stability of oil from belly flaps of Nile perch (*Lates niloticus*). Food Chem., 108: 103-109.

Okedi JO (2005). A Historical perspective of the challenges and opportunities in management of the Lake Victoria fisheries: Lessons for the future. Proceedings of the Regional Stakeholders' Conference, Imperial Resort Beach Hotel, Entebbe 24th-25th February, 2005.

Osman IJ, Khaza'ai H, Ridzwan H (2007). Fatty acid profiles of fin fish in Langkawi island, Malaysia. J. Oleo. Sci., 56: 107-113.

Rimmer MA, Reed A (1989). Effects of nutritional enhancement of live food organisms on growth and survival of Barramundi/Seabass *Lates calcarifer* (Bloch) larvae. Adv. Trop. Aquacult., 9: 611-623.

Sargent JR, Bell JG, Henderson RJ, Tocher DR (1995). Requirement criteria for essential fatty acids. J. Appl. Ichthyol., 11: 183-198.

Sargent JR, McEvoy L, Estevez A, Bell G, Henderson J, Tocher D (1999). Lipid nutrition of marine fish during early development: Current status and future directions. Aquaculture, 179: 217-229.

Sorbera LA, Asturiano JF, Carrillo M, Zanuy S (2001). Effects of polyunsaturated fatty acids and prostaglandins on oocyte maturation in a marine teleost, the European sea bass (*Dicentrarchus labrax*). Biol. Reprod., 64: 382-389.

Steffens W (1997). Effects of variation in essential fatty acids in fish feeds on nutritive value of freshwater fish for humans. Aquaculture, 119: 63-88.

Tang H, Chen L, Xiao C, Wu T (2009). Fatty acid profiles of muscle from large yellow croaker (*Pseudosciaena crocea* R.) of different age. J. Zhejiang Univ. Sci., 10: 154-158.

Tocher DR (2003). Metabolism and function of lipids and fatty acids in teleost fish. Rev. Fish Sci., 11: 107-184.

Tocher DR, Dick JR (2004). Essential fatty acid deficiency in freshwater fish: The effects of linoleic, α-linolenic, γ-linolenic and stearidonic acids on metabolism of [1-14C] 18:3n-3 in a carp cell model. Fish Physiol. Biochem., 22: 67-75.

Turon F, Rwabwogo B, Baréa B, Pina M, Graille J (2005). Fatty acid composition of oil extracted from Nile perch (*Lates niloticus*) head. J. Food Compos. Anal., 18: 717-722.

Ugoala C, Ndukwe GI , Audu TO (2008). Comparison of Fatty Acids profile of some freshwater and marine fishes. Internet J. Food Saf., 10: 9-17.

Ugoala C, Ndukwe GI, Audu TO (2009). Fatty acids composition and nutritional quality of some freshwater fishes. Nature Precedings: doi: 10.1038/npr.2009.3239.1: posted 12 May, 2009.

Uotani I, Saito T, Hiranuma K, Nishikawa Y (1990). Feeding habit of bluefin tune *Thunnus thynnus* larvae in the western North Pacific Ocean. Nippon Suisan Gakkaishi, 56: 713-717.

Watanabe T, Kiron V (1994). Prospects in larval fish dietetics. Aquaculture, 124: 223-253.

Yanes-Roca C, Rhody N, Nystrom M , Main KL (2009). Effects of fatty acid composition and spawning season patterns on egg quality and larval survival in common snook (*Centropomus undecimalis*) Aquaculture, 287: 335-340.

Yu TC, Sinnhuber RO (1975). Effect of dietary linolenic and linoleic acids upon growth and lipoid metabolism of rainbow trout (*Salmo gairdneri*). Lipids, 10: 63-66.