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The fatty acid profiles and energetic substrates of two Nile tilapia (*Oreochromis niloticus*, Linnaeus) strains, Red-Stirling and Chitralada, and their hybrid

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Abstract

Protein and lipid content as well as the fatty acid (FA) composition of storage tissues were analysed in two varieties of *Oreochromis niloticus* (Red-Stirling and Chitralada) and their hybrid. The animals were maintained in cages for 11 months. The samples were taken when the animals weighed 10, 50, 100, 250 and 500 g. The results showed that changes in the metabolic processes occur during an increase in body mass in both varieties of tilapia and also their hybrid, but that these differences are not found in animals collected at the commercial weight. The protein content of the fillet and liver decreased with growth and the same protein content associated with growth was found for fillet lipid content. The genetic variety did not influence the FA profile of the fillet, but different genotypes had different hepatic FA compositions. Even with the same lipid content, the hepatocytes of Chitralada accumulated higher levels of polyunsaturated fatty acids (PUFA) n6 in triglycerides and increased C22:6n3 in the hepatocyte membranes. The higher n6PUFA content was compensated by a lower fraction of saturated FA in the hepatocyte triglycerides. The skin of Chitralada also had higher n6PUFA and C22:6n3 contents, suggesting a higher ability to deposit PUFA in the skin due to alterations in the liver synthetic pathway.

Keywords: Red-Stirling, fatty acids, Chitralada, liver, tilapia, protein,

Introduction

The search for food of animal origin with low cholesterol levels and high protein levels has led to an increase in the inclusion of fish in the daily menu worldwide and has increased the demand and search for new sources of fish to supply the market. Aquaculture is one of these sources, but to meet the nutritional requirements necessary for the market, fish produced in captivity should have the same nutritional values as wild species. This is an important issue for food companies' market strategies as consumers are currently concerned about purchasing products with satisfactory nutritional quality (13Food and Agriculture Organization 2006). The main parameters desirable in farmed fish are a high protein content and low lipid levels (mainly cholesterol), with high proportions of polyunsaturated fatty acids (PUFA) (El-Dahhar 1997) in the fillet.

Most fish are usually a rich source of ω-3 (n3) and ω-6 (n6) PUFA. However, this profile depends on the species, the climate and the diet available. The best fatty acid (FA) profile required for human consumption is more often found in wild fish than in farmed fish, as in captivity, they are fed with manufactured diets, which are prepared mainly with vegetable oils and saturated fats. Some studies have shown that farmed fish, including tilapia, have low amounts of the main PUFA [n3, α-linolenic acid, eicosapentaenoic acid and docosahexaenoic acid (DHA)] compared with wild fish (Justi, Hayashi, Visentainer,

Souza & Matsushita 2003; Luzia, Sampaio, Castelucci & Torres 2003). ω-3 FAs have positive effects on health, and adequate intake of these FAs, together with the ω-6 FAs, may reduce the risk of many diseases such as hypertension, diabetes, arthritis and other inflammatory disorders and cancers (Howe 1997; Wahlquist 1998; Krishna Mohan & Das 2001; Colquhoun, Miyake & Benadiba 2009).

Tilapias comprise a group of African cichlids, with some species raised in different regions of the world. Nile tilapia (*Oreochromis niloticus*) is the most important commercially cultured tilapia species worldwide. Nile tilapia has many important biological characteristics for aquaculture. They grow quickly in captivity, tolerate higher density conditions and intensive management systems, feed mainly on phytoplankton or benthic algae and accept a wide range of feeding from manures and agricultural by-products to manufactured feeds (Beveridge & McAndrew 2000). Also, the fillet yield (35%), low fat (0.9 g/100 g), few calories (172 kcl/100 g) and lack of bones have resulted in the Nile tilapia being widely consumed (Clement & Lovell 1994).

Currently, genetic breeding programmes are being conducted through intra-specific diallelic crosses, followed by selection (Bentsen, Eknath, Palada De Vera, Danting, Bolivar, Reyes, Dionisio, Longalong, Circa, Tayamen & Gjerde 1998) and also by inter-specific crosses (Moreira, Moreira & Hilsdorf 2005). These genetic breeding programmes aimed to achieve superior strains for the aquaculture industry.

Some authors have recognized that different genetic strains may be the reason for the different patterns of substrate deposition in salmonids (Shearer 1994) and tilapias (Garduño-Lugo, Granados-Alvarez, Olvera-Novoa & Muñoz-Córdova 2003; Garduño-Lugo, Herrera-Solis, Ângulo-Guerrero, Muñoz-Cordóva & Cruz-Medina 2007). Therefore, the nutritional content may be a parameter to be culled in genetic breeding programmes, and may result in knowledge of the chemical composition of the tissues and organs according to sex, age and genetic background. This would be an important step in establishing a selection index.

Fish fillets are an important source of PUFA for human nutrition, and genetic characteristics can alter the chemical composition of many fish species. Therefore, the aim of the present study was to analyse the FA profile, the protein content and the lipid content of two strains of *O. niloticus* (Red-Stirling and Chitralada) and their intra-specific hybrid raised in cage systems.

Materials and methods

Experimental procedures and feeding

A total of 5400 tilapia were placed in nine cages (1.5 × 1.5 × 1.5 m, volume of 3.375 m^3) at a storage density of 177 fish m^{-3} (600 fish $cage^{-1}$) at the Brazilian Industry aquaculture facilities (Jundiaí city, SP, Brazil). All animals were males obtained by sex reversal through the administration of the androgen steroid 17-α-methyltestosterone (MT) in the diet (60 mg MT kg^{-1} of diet for 28 days).

Three experimental groups were established: Red-Stirling, Chitralada and their hybrid (male Red-Stirling × female Chitralada). The two strains were genetically evaluated by microsatellite markers, which showed a significant genetic differentiation between both stains ($R_{ST} = 0.130$, $P < 0.05$) (Moreira, Silva, Souza & Hilsdorf 2007). They were maintained in triplicate in cages distributed randomly in a 10-hectare reservoir. The tilapia were fed daily with an extruded commercial feed (crude protein 32%, crude lipids 6.5%, moisture 8%, fibre mixture 7%, mineral mixture 10%, calcium 1.2%, phosphorus 0.6%, vitamin C 0.32%), and both the dissolved oxygen and the water temperature were monitored daily in the morning and afternoon using an oximeter (model 55; YSI, Yellow Springs, OH, USA). Additionally, samples of water were collected, centrifuged and filtered in a laminar flux using a 0.22 μm Millipore filter (Billerica, MA, USA), and FAs retained in the filter were analysed (Table 1). The FA profile of the diet was also determined (Table 2).

During the experimental period (11 months, from March 2006 to February 2007), the animals were fed to apparent satiety two times a day. The fish were sampled from the cages when the average body mass was around 10, 50, 100, 250 and 500 g. Five animals from each cages (15 from each group) were collected for sampling. Animals with a body mass of 10 g were collected in March 2006 (early autumn), 50 g in May (mid-autumn), 100 g in August (end of the winter), 250 g in November (mid-spring) and 500 g in February (mid-summer).

The fish were caught and anaesthetized with a benzocaine solution diluted at a concentration of 70 mg L^{-1}. Blood samples were immediately collected using heparinized syringes (Liquemine, Roche®, Rio de Janeiro, RJ, Brazil) and needles by puncturing the caudal vasculature. Blood samples were centrifuged at 655.1 g for 10 min, and the plasma was separated into aliquots, which were immediately frozen in dry ice and preserved at − 80 °C until processing.

Table 1 Fatty acid profile of total lipids in the water

Fatty acid	%
14:0	2.5
16:0	43.1
17:0	1.1
18:0	4.3
20:0	1.3
ΣSFA	52.3
16:1n7	5.1
17:1n9	2.7
18:1n9	13.1
ΣMUFA	20.9
18:2n6	6.7
18:3n6	5.1
22:5n6	3.2
Σn6	15.0
18:3n3	7.2
18:4n3	3.3
22:6n3	1.3
Σn3	11.8
ΣPUFA	26.8
n3/n6	0.8

SFA, saturated fatty acid; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

Table 2 Fatty acid profile of the experimental diets

Fatty acid	%
14:0	1.0
15:0	0.2
16:0	15.7
17:0	0.8
18:0	12.0
20:0	1.4
21:0	0.2
22:0	0.9
23:0	0.2
24:0	1.3
ΣSFA	33.7
14:1n5	0.1
16:1n7	1.3
17:1n9	0.2
18:1n9	28.2
18:1n7	2.3
20:1	0.6
24:1	0.2
ΣMUFA	33.0
18:2n6	28.7
18:3n6	0.3
20:2n6	0.2
22:2n6	0.3
22:4n6	0.1
Σn6	29.8
18:3n3	2.2
20:3n3	0.4
20:5n3	0.1
22:5n3	0.5
22:6n3	0.3
Σn3	3.5
ΣPUFA	33.3
n3/n6	0.1

SFA, saturated fatty acid; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

After blood collection, fish were killed by cutting the section of the spinal cord next to the operculum, the weight and length were recorded and portions of the skin, portions of the fillet, the whole liver and portions of the adipose tissue were removed. Tissues were placed in cryovials and zip-lock bags, immediately frozen in dry ice and kept at − 80 °C until processing.

Tissue analysis

Crude protein

The protein content of tissue (fillet and liver) and plasma was determined using the colorimetric method of Lowry, Rosenbrough, Farr and Randall (1951). Precipitation and solubilization of the total protein in the muscle and in the liver was performed according to Milligan & Girard's (1993) method. The concentration of protein was calculated using a standard curve of bovine serum albumin (Sigma Diagnostics, St Louis, MO, USA) at 660 nm.

Crude lipids

The total lipids of the fillet, skin and liver were extracted with a mixture of chloroform, methanol and water (2:1:0.5) according to Folch, Less and Sloane Stanley (1957) and adapted by Parrish (1999). Total lipids in the fillet and liver were quantified using the enzyme-colorimetric method described by Frings, Fendly Dunn and Quenn (1972) using cod liver oil (Sigma Diagnostics) as a standard at 540 nm.

Moisture

The analysis of moisture in the fillet was performed with 500 g of fish using about 100 mg of tissue, which was initially weighed and then placed in an oven (105 °C) for approximately 24 h until it had a constant weight. The tissue was removed from the oven and cooled in a desiccator until it reached room temperature and the final weight was determined. The difference found between the initial and the final weight was expressed as the percentage of moisture in the tissue (Instituto Adolfo Lutz 1985).

FA profile

The lipid extracts (as described above) of the animal tissues at the end of the experiment (500 g) were separated into polar lipids (phospholipids) and neutral lipids (triglycerides) using an activated silica column (Yang 1995). Methylation of each fraction was performed with acetyl chloride (5% HCl in methanol) (Christie 2003), and FA composition was determined as methyl esters using a Varian Model 3900 Gas Chromatograph (Walnut Creek, CA, USA) coupled with flame ionization detection (FID). Fatty acids were identified by comparing the retention time using a known standard of fatty acids methyl esters (FAME) (Supelco, 37 components; Sigma-Aldrich (Chicago, IL, USA) and Mixture Me93, Qualmix PUFA fish M, and Menhaden Oil, Larodan, Malmö, Sweden). The FAME was analysed on a capillary column (CP Wax 52 CB, Varian, Lake Forest, CA, USA; 0.25 μm thickness, inside diameter 0.25 mm and 30 m length). Hydrogen was used as a carrier gas at a linear velocity of 22 cm s^{-1}. The temperature program was 170 °C for 1 min, followed by a 2.5 °C min^{-1} ramp up to 240 °C, and a final hold time of 5 min. Injector and FID temperatures were 250 and 260 °C respectively.

Statistical analysis

The FA profiles, lipids and protein content of the storage tissues were compared between strains using an analysis of variance (one-way ANOVA), followed by the Holm–Sidak *t*-test for parametric analysis and Dunn's test for non-parametric analysis. The one-way ANOVA was chosen to analyse the fish strain and the body mass as separate variables in two distinct analyses. For all analyses, differences were considered to be significant when $P < 0.05$. These analyses were performed using the statistical software SIGMASTAT for Windows ver. 3.10 (Systat Software, San Jose, CA, USA).

Results

Food and Water Quality

The FA analyses of the diet (Table 2) showed the presence of 3% of n3PUFA and 30% of n6PUFA, with linoleic acid (C18:2n6) contributing 28.7% of the PUFA. Saturated (SFA) and monounsaturated fatty acids (MUFA) each represent around 33% of the total FAs.

In contrast, in plankton (Table 1), the SFA represents more than half of the total FA (52.3%), and palmitic acid (C16:0) is the main FA found (43.1%). Monounsaturated fatty acids comprises 20.81% (C18:1n9, oleic acid, is the main MUFA, with 13.06 %) and PUFA 26.81% (the main FA are C18:2n6, C18:3n6 and C18:3n3).

The water temperature ranged from 18.5 °C (09:00 hours, during winter) to 25.8 °C (15:00 hours, during the summer) and dissolved oxygen in the water ranged from 4.8 mg L^{-1} (9:00 am, during summer) to 8.8 mg L^{-1} (3:00 pm, during winter).

Fish body composition

The data presented in Table 3 show the protein content in the fillet, liver and plasma for each of the three varieties during the growth period. The Red-Stirling tilapia accumulated more protein in the fillet in the first phase of growth (50 g) when compared with the other groups. When Red-Stirling tilapia reached 100 g, the muscle protein decreased, whereas in Chitralada and hybrids, this decrease occurred when animals reached 250 g. However, when the commercial size was reached (500 g), there was no difference in the protein content in the fillet.

The hepatic protein content in Red-Stirling and Chitralada decreased when the animals increased in body mass from 250 to 500 g, but for the hybrids, this was beyond significance ($P > 0.05$). Because of this sharp decrease in hepatic protein, the parental species presented a lower protein content at 500 g when

Table 3 Concentration of total protein in the fillet (%), liver (%) and plasma (mg mL^{-1}) of *Oreochromis niloticus*, Red-Stirling, hybrid and Chitralada (mean ± SEM)

Fish weight	Red-Stirling	Hybrid	Chitralada
Fillet (g)			
10	16.6 ± 0.70^{a}	16.8 ± 0.54^{a}	18.0 ± 0.86^{a}
50	23.2 ± 1.04$^{\#b}$	17.6 ± 0.79^{*a}	19.0 ± 0.45^{*a}
100	18.6 ± 0.59^{a}	18.5 ± 0.44^{a}	19.4 ± 0.40^{a}
250	16.3 ± 0.18^{a}	13.2 ± 1.62^{b}	15.1 ± 1.81^{b}
500	14.1 ± 0.45^{a}	13.7 ± 0.07^{b}	12.1 ± 0.50^{b}
Liver (g)			
100	7.6 ± 0.57^{*a}	10.6 ± 0.31$^{\#a}$	10.8 ± 1.02$^{\#a}$
250	13.1 ± 0.51$^{\#b}$	12.4 ± 0.54^{*a}	12.3 ± 0.44^{*a}
500	8.9 ± 0.63^{*a}	10.1 ± 0.33$^{\#a}$	4.70 ± 0.90^{*b}
Plasma (g)			
250	43.2 ± 4.50	37.7 ± 3.20^{a}	37.1 ± 3.70^{a}
500	56.7 ± 5.50	54.9 ± 2.30^{b}	49.9 ± 4.20^{b}

Different symbols indicate statistical differences ($P < 0.05$) between the strains (horizontal).
Different letters indicate statistical differences ($P < 0.05$) between body mass (vertical).

Table 4 Concentration of total lipids in the fillet and liver (%) of *Oreochromis niloticus*, Red-Stirling, hybrid and Chitralada (mean ± SEM)

Fish weight	Red-Stirling	Hybrid	Chitralada
Fillet (g)			
10	1.0 ± 0.04^{a}	1.0 ± 0.07^{a}	1.1 ± 0.06^{a}
50	1.2 ± 0.07^{a}	1.4 ± 0.17^{a}	1.0 ± 0.09^{a}
100	0.6 ± 0.05^{*b}	0.6 ± 0.05^{*b}	0.4 ± 0.03$^{\#b}$
250	0.3 ± 0.04^{*c}	0.1 ± 0.01$^{\#c}$	0.2 ± 0.02$^{\#*ac}$
500	0.5 ± 0.11^{bc}	0.2 ± 0.06^{c}	0.3 ± 0.04^{bc}
Liver (g)			
100	4.1 ± 0.30^{a}	4.4 ± 0.41^{a}	3.5 ± 0.27^{a}
250	1.5 ± 0.29^{b}	2.0 ± 0.29^{b}	1.8 ± 0.28^{b}
500	2.6 ± 0.24^{b}	2.4 ± 0.33^{b}	2.2 ± 0.34^{b}

Different symbols indicate statistical differences ($P < 0.05$) between the strains (horizontal).
Different letters indicate statistical differences ($P < 0.05$) between body mass (vertical).

Table 5 Moisture in fillets (%) of *Oreochromis niloticus*, Red-Stirling, hybrid and Chitralada (mean ± SEM)

Fish weight (g)	Red-Stirling	Hybrid	Chitralada
10	73 ± 2.0	73 ± 4.0	68 ± 0.6
50	68 ± 2.3	71 ± 3.7	71 ± 3.7
100	65 ± 2.0	75 ± 3.4	78 ± 4.1
250	72 ± 1.8	74 ± 4.5	67 ± 1.2
500	68 ± 1.2	81 ± 3.4	78 ± 3.6

compared with the hybrids. The decrease in hepatic protein from 250 to 500 g was followed by an increase in plasma protein in Chitralada and hybrid tilapias.

The data presented in Table 4 show the lipid content in the fillet and liver versus growth in the three varieties. The data showed that in fillet, the lipid content decreased throughout the growth period but most drastically between 50 and 250 g when these values were maintained constant. The comparison made between the groups showed that in some growth periods, muscle lipid content was different depending on the group considered. An example is shown with 100 g specimens, where Chitralada presented with a lower fillet lipid content than Red-Stirling and hybrids, and with 250 g, where the hybrids presented a lower muscle lipid content. However, in the same way as the protein content, when animals reached the commercial size, no differences in the fillet lipid content were found when comparing the three strains. Similarly, in the liver, there was a sharp decrease in lipids when the animals' body mass increased from 100 to 250 g, and the lipid content remained constant in the 500 g animals. No differences in hepatic lipids were found among the three groups. The comparison of lipid content in the liver and fillet showed that the liver stores more lipids than fillet throughout all phases of growth.

The wet content of the fillet ranged from 65% to 81% in the three groups, without significant differences within each group (Table 5).

The FA profiles of the animal tissues were determined when they reached the commercial size. The FA profile of the fillet is presented in Table 6. In the neutral fraction, Red-Stirling had a higher percentage of C18:0 ($P < 0.05$) when compared with Chitralada and hybrid tilapias. C16:1 was higher in hybrid fish when compared with Red-Stirling. In the polar fraction, no differences in the FA content were found among the different strains.

The liver FA profile is presented in Table 7. The results showed that in the neutral fraction, Chitralada had a higher percentage of C20:1 when compared with Red-Stirling. The same was observed for n6PUFA, due to higher amounts of C18:2n6, C20:2n6, C20:3n6 and 22:4n6. The profile of the hybrids was more similar to Red-Stirling than Chitralada. The C20:4n6/C18:3n6 ratio in the liver neutral fraction was higher in hybrids than Chitralada, but did not differ from Red-Stirling.

In the liver polar fraction, Red-Stirling showed a decrease in the percentage of total PUFA when compared with Chitralada and hybrids. This difference occurred because the percentage of n3PUFA, mainly C22:6n3, decreased the n3/n6 ratio in the Red-Stirling. Even with no differences in total SFA, C14:0 was also higher in Red-Stirling fish when compared with Chitralada (Table 8).

In adipose tissue (Table 8), the main alterations observed were in MUFA, which were higher in Chitralada when compared with Red-Stirling and hybrids. This increase was mainly due to an increase in C20:1 and C18:1, the main MUFA in adipose tissue. Saturated fatty acid and PUFA were not altered in adipose tissue according to genotype. Plasma PUFA were higher in Chitralada when compared with Red-Stirling, due to an increase in n3PUFA, mainly DHA (Table 9).

The FA profile of total lipids in skin is presented in Table 10. The data presented emphasize that Chitralada present different FA profiles in skin when compared with Red-Stirling. Chitralada had a lower percentage of SFA in skin than Red-Stirling, mainly due to differences in C14:0 and a higher percentage of total PUFA. The primary PUFA in Chitralada was

Table 6 Fatty acid profiles of the neutral and polar fractions in fillets of *Oreochromis niloticus*, Red-Stirling, hybrid and Chitralada, (mean ± SEM)

	Fillet					
	Neutral fraction			Polar fraction		
Fatty acid (%)	Red-Stirling	Hybrid	Chitralada	Red-Stirling	Hybrid	Chitralada
14:0	2.30 ± 0.18	2.42 ± 0.10	2.39 ± 0.3	0.94 ± 0.2	0.83 ± 0.2	0.58 ± 0.1
16:0	22.8 ± 0.40	23.5 ± 0.60	22.4 ± 1.3	17.8 ± 1.1	16.5 ± 1.4	17.1 ± 2.2
18:0	8.25 ± 0.19[a]	6.73 ± 0.08[b]	6.04 ± 0.17[b]	12.1 ± 1	11.7 ± 0.6	11.8 ± 0.2
ΣSFA	33.2 ± 2.19	32.6 ± 1.42	30.8 ± 1.56	30.8 ± 2.5	29.0 ± 1.4	29.5 ± 1.9
16:1n7	3.75 ± 0.18[a]	5.00 ± 0.15[b]	4.49 ± 0.26[ab]	1.37 ± 0.2	1.38 ± 0.1	1.62 ± 0.40
18:1n9	37.8 ± 3.03	36.7 ± 1.63	35.8 ± 1.24	16.3 ± 1.6	14.1 ± 1.2	17.0 ± 2.7
20:1n9	2.18 ± 0.18	0.93 ± 0.19	1.53 ± 0.35	ND	ND	ND
ΣMUFA	43.5 ± 2.98	42.8 ± 1.58	41.8 ± 1.22	17.7 ± 1.9	15.5 ± 1.4	18.6 ± 2.2
18:2n6	16.5 ± 0.31	16.9 ± 0.32	17.1 ± 0.46	12.1 ± 0.8	12.3 ± 0.7	11.7 ± 0.7
18:3n6	1.09 ± 0.13	1.23 ± 0.11	1.39 ± 0.08	1.53 ± 0.4	1.19 ± 0.2	1.12 ± 0.3
20:2n6	0.90 ± 0.17	0.8 ± 0.17	1.13 ± 0.04	1.39 ± 0.2	1.26 ± 0.1	2.02 ± 0.2
20:3n6	0.90 ± 0.07	1.04 ± 0.03	1.03 ± 0.07	1.95 ± 0.1	2.33 ± 0.1	2.30 ± 0.2
20:4n6	0.23 ± 0.04	ND	0.16 ± 0.01	1.59 ± 0.4	0.93 ± 0.2	ND
22:4n6	0.82 ± 0.06	0.88 ± 0.60	0.92 ± 0.09	3.98 ± 0.9	3.67 ± 0.2	3.51 ± 0.6
22:5n6	0.79 ± 0.07	0.74 ± 0.08	0.86 ± 0.08	8.00 ± 1.1	8.26 ± 0.5	8.46 ± 0.8
Σn6	20.6 ± 0.62	21.6 ± 0.39	22.6 ± 0.43	30.6 ± 2.4	30.0 ± 1.1	29.1 ± 1.9
18:3n3	1.33 ± 0.18	1.37 ± 0.11	1.37 ± 0.07	ND	0.62 ± 0.1	0.64 ± 0.1
20:3n3	0.23 ± 0.04	ND	0.16 ± 0.01	8.84 ± 1.3	10.1 ± 0.8	10.2 ± 1.1
22:5n3	0.46 ± 0.10	0.50 ± 0.12	0.40 ± 0.04	2.64 ± 1.2	1.96 ± 0.2	2.37 ± 0.4
22:6n3	0.83 ± 0.10	0.90 ± 0.08	0.89 ± 0.12	7.54 ± 0.8	8.37 ± 0.9	7.93 ± 0.9
Σn3	2.78 ± 1.2	2.77 ± 1.00	2.82 ± 0.60	19.0 ± 2.1	21.0 ± 1.5	21.1 ± 2.1
ΣPUFA	23.4 ± 0.9	24.4 ± 0.54	25.4 ± 0.57	49.6 ± 2.2	51.0 ± 2.1	50.2 ± 4
n3/n6	0.13 ± 0.1	0.12 ± 0.05	0.12 ± 0.02	0.62 ± 0.1	0.70 ± 0.1	0.72 ± 0

Different letters indicate statistical differences ($P < 0.05$) between strains (horizontal).
Not detected.
SFA, saturated fatty acid; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

n6 due to long-chain n6PUFA (LC-PUFA), C20:4n6, C22:2n6, C22:4n6 and C22:5n6 when compared with Red-Stirling. It is also important to highlight that Chitralada had a higher percentage of C22:6n3 in the skin when compared with Red-Stirling animals; however, this difference is not reflected in total n3PUFA due to a decreased tendency (not significant) in C18 n3PUFA. In most of the FA analysed in the skin, the hybrid tilapias presented no statistical difference with the parental species, except that C20:3n3 was lower than that in Red-Stirling and was not detected in Chitralada.

Discussion

The influence of the different tilapia strains on metabolic substrates was analysed relative to growth, with an emphasis on the FA composition of the fish at commercial size.

The protein content of the fillet and liver decreased relative to the growth in the three experimental groups analysed. This decrease in muscle protein is believed to be due to the use of this energetic substrate for growth, particularly during the winter period faced by the animals. The fillet protein content in the three groups was similar to those found by Garduño-lugo, Herrera-solis, Ângulo-guerrero, Muñoz-cordóva and Cruz-medina (2007) in Nile tilapia and a red hybrid, and these authors also did not find differences in the protein content in the fillet considering these different strains. In the present work, the only differences in the protein content found between the genotypes were in the liver, but these differences were without a clear pattern. The Red-Stirling accumulated less protein in the liver at 100 g, but when the animals reached 250 g, they had a higher protein content. At commercial size, the hybrids had a higher liver protein content. According to Pádua (1996), the increase in body mass is followed by a decrease in the

Table 7 Fatty acid profiles of neutral and polar fraction in liver of *Oreochromis niloticus*, Red-Stirling, hybrid and Chitralada (mean ± SEM)

	Liver					
	Neutral fraction			Polar fraction		
Fatty acid (%)	Red-Stirling	Hybrid	Chitralada	Red-Stirling	Hybrid	Chitralada
14:0	4.48 ± 0.77	3.10 ± 0.46	1.99 ± 0.41	1.73 ± 0.16^{a}	1.10 ± 0.07^{ab}	0.87 ± 0.07^{b}
16:0	28.8 ± 1.09	25.8 ± 1.58	22.5 ± 1.43	16.2 ± 0.66	16.1 ± 0.94	14.9 ± 0.79
18:0	26.0 ± 2.34^{a}	17.6 ± 4.40^{ab}	11.4 ± 1.51^{b}	12.9 ± 0.78	12.7 ± 0.55	13.3 ± 0.64
ΣSFA	60.8 ± 2.24^{a}	48.4 ± 5.88^{b}	38.1 ± 1.62^{b}	31.4 ± 0.94	30.4 ± 0.98	30.0 ± 0.64
16:1n7	5.88 ± 0.62	5.34 ± 0.41	4.76 ± 0.42	3.55 ± 0.39	2.65 ± 0.30	2.51 ± 0.31
18:1n9	22.2 ± 1.38	31.5 ± 4.99	34.7 ± 4.41	21.1 ± 1.62	17.1 ± 0.87	16.5 ± 1.62
20:1n9	0.15 ± 0.01^{a}	0.18 ± 0.01^{ab}	0.29 ± 0.02^{b}	ND	ND	ND
ΣMUFA	28.3 ± 1.77	37.5 ± 4.95	40.1 ± 1.47	24.7 ± 2.01	19.9 ± 1.12	19.1 ± 1.94
18:2n6	7.18 ± 0.89^{a}	8.19 ± 1.12^{a}	13.5 ± 1.15^{b}	9.17 ± 0.52	7.87 ± 0.53	8.44 ± 0.83
18:3n6	0.42 ± 0.04^{a}	0.49 ± 0.04^{a}	0.89 ± 0.11^{b}	0.62 ± 0.02	0.57 ± 0.01	0.68 ± 0.05
20:2n6	0.42 ± 0.06^{a}	0.62 ± 0.09^{ab}	0.89 ± 0.08^{b}	1.24 ± 0.07	1.32 ± 0.09	1.42 ± 0.05
20:3n6	0.27 ± 0.04^{a}	0.49 ± 0.07^{ab}	0.70 ± 0.08^{b}	2.04 ± 0.10	2.26 ± 0.15	2.06 ± 0.22
20:4n6	0.58 ± 0.12	1.31 ± 0.32	1.28 ± 0.35	9.46 ± 0.45	9.46 ± 0.41	10.6 ± 0.43
22:4n6	0.24 ± 0.03^{a}	0.46 ± 0.09^{a}	0.72 ± 0.11^{b}	3.05 ± 0.25	3.58 ± 0.30	3.52 ± 0.40
22:5n6	0.33 ± 0.06	0.77 ± 0.19	0.91 ± 0.26	8.69 ± 0.84	8.98 ± 0.50	9.23 ± 0.49
Σn6	9.45 ± 1.10^{a}	12.3 ± 1.69^{a}	19.2 ± 2.37^{b}	34.3 ± 1.51	34.1 ± 1.36	36.0 ± 0.69
18:3n3	0.63 ± 0.17	0.71 ± 0.12	1.20 ± 0.12	0.47 ± 0.07	0.52 ± 0.06	0.65 ± 0.10
20:5n3	ND	ND	ND	ND	0.26 ± 0.01	0.35 ± 0.16
22:5n3	0.19 ± 0.08	0.23 ± 0.04	0.31 ± 0.05	1.46 ± 0.07	2.11 ± 0.22	2.11 ± 0.19
22:6n3	0.29 ± 0.06	0.78 ± 0.21	0.78 ± 0.30	7.72 ± 0.66^{a}	12.4 ± 0.90^{b}	11.5 ± 1.54^{b}
Σn3	0.98 ± 0.31	1.68 ± 0.33	2.38 ± 0.51	9.42 ± 0.75^{a}	15.1 ± 1.05^{b}	14.6 ± 1.70^{b}
ΣPUFA	10.4 ± 1.47^{a}	14.0 ± 1.98^{a}	21.8 ± 2.84^{a}	43.7 ± 1.77^{a}	49.2 ± 1.67^{b}	50.6 ± 1.76^{b}
n3/n6	0.11 ± 0.01	0.13 ± 0.01	0.12 ± 0.01	0.27 ± 0.02^{b}	0.44 ± 0.03^{b}	0.40 ± 0.05^{b}
18:3n6/18:2n6	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.26	0.06 ± 0.02	0.07 ± 0.03	0.08 ± 0.02
20:4n6/18:3n6	1.35 ± 0.26^{ab}	2.61 ± 0.53^{a}	1.24 ± 0.27^{b}	15.3 ± 5.66	16.6 ± 5.02	15.8 ± 8.18

Different letters indicate statistical differences ($P < 0.05$) between strains (horizontal).
ND, Not detected.
SFA, saturated fatty acid; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

water content and an increase in the lipid content, and this author suggests that minimum alterations in proteins and minerals content accompany growth. On the contrary, in Nile tilapia and the Red hybrid, Garduño-Lugo *et al.* (2007) did not find differences in fillet moisture in the different strains, corroborating the results of the present study.

The changes in the protein content in the fillet during growth were comparable to the changes in the lipid content. There was a decrease in the fillet lipid content with growth, which was more evident when the body mass increased from 50 to 100 g, coincidently between May and August (during winter). However, even during spring, when the body mass changed from 100 to 250 g, the lipid content in muscle decreased again and then was constant until the fish weighed 500 g (summer). According to Rasoarahona, Barnathan, Bianchini and Gaydou (2005), tilapia muscle lipid content decreases between autumn and winter, corroborating the data of the present study collected during the animals' body mass increase from 50 to 100 g. These authors found that in *O. niloticus* with a body mass varying from 100 to 250 g, the lipid content was higher in autumn and lower in winter. We suggest that at lower temperatures, higher oxygen solubility can be important in driving the use of this metabolic substrate to produce energy.

It is important to highlight that the lipid content found in all of the experimental groups in this study was below those described by Garduño-Lugo *et al.* (2007) in Stirling (0.97%, or 9.7 mg g^{-1}) and in the red hybrid (0.70% or 7 mg g^{-1}). Both experimental groups were fed with a diet containing 14.6% crude lipid, more than twice the amount used in the present study (6.5%). Additionally, in the experiment conducted by Garduño-Lugo *et al.* (2007), the stocking density was lower (7 fish m^{-3}) than the present study, suggesting that in a small swimming area, the animals use more lipid from muscle.

Table 8 Fatty acid profiles of adipose tissue of *Oreochromis niloticus*, Red-Stirling, hybrid and Chitralada (mean SEM)

	Adipose tissue		
Fatty acid (%)	Red-Stirling	Hybrid	Chitralada
14:0	2.14 ± 0.14	1.98 ± 0.11	2.00 ± 0.14
16:0	20.7 ± 0.34	20.7 ± 0.38	21.0 ± 0.48
18:0	45.1 ± 0.48^{a}	43.8 ± 0.49^{ab}	32.9 ± 2.14^{b}
ΣSFA	70.7 ± 0.55^{a}	69.3 ± 0.33^{ab}	58.9 ± 2.40^{b}
16:1n7	3.86 ± 0.11	4.37 ± 0.16	4.52 ± 0.25
18:1n9	16.6 ± 0.45^{a}	17.3 ± 0.58^{a}	26.8 ± 2.53^{b}
20:1n9	0.30 ± 0.01^{ab}	0.26 ± 0.01^{a}	0.35 ± 0.01^{b}
ΣMUFA	21.1 ± 0.66^{a}	22.3 ± 0.57^{a}	32.1 ± 2.23^{b}
18:3n6	0.88 ± 0.04^{a}	0.95 ± 0.02^{ab}	1.13 ± 0.03^{b}
20:2n6	1.12 ± 0.1	1.04 ± 0.09	1.12 ± 0.24
20:3n6	0.71 ± 0.04	0.73 ± 0.02	0.76 ± 0.05
20:4n6	0.76 ± 0.02	0.77 ± 0.02	0.83 ± 0.05
22:4n6	0.66 ± 0.05	0.68 ± 0.03	0.72 ± 0.08
22:5n6	0.67 ± 0.04	0.62 ± 0.02	0.64 ± 0.08
Σn6	5.10 ± 0.32	5.25 ± 0.16	5.56 ± 0.36
18:3n3	1.52 ± 0.19	1.60 ± 0.09	1.65 ± 0.14
22:5n3	0.31 ± 0.04	0.30 ± 0.01	0.31 ± 0.04
22:6n3	0.49 ± 0.05	0.45 ± 0.02	0.45 ± 0.07
Σn3	2.94 ± 0.11	3.08 ± 0.08	3.06 ± 0.19
ΣPUFA	8.05 ± 0.42	8.33 ± 0.24	8.62 ± 0.55
n3/n6	0.58 ± 0.02	0.58 ± 0.01	0.55 ± 0.01

Different letters indicate statistical differences ($P < 0.05$) between strains (horizontal).
Not detected.
SFA, saturated fatty acid; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

Table 9 Fatty acid profiles of plasma of *Oreochromis niloticus*, Red-Stirling, hybrid and Chitralada (mean ± SEM)

	Plasma		
Fatty acid (%)	Red-Stirling	Hybrid	Chitralada
14:0	2.66 ± 0.49	1.78 ± 0.17	1.81 ± 0.16
16:0	21.0 ± 1.36	19.8 ± 0.92	18.4 ± 0.86
18:0	8.24 ± 0.55	6.97 ± 0.33	7.89 ± 0.37
ΣSFA	34.0 ± 5.49	31.5 ± 2.90	28.1 ± 1.47
16:1n7	3.11 ± 0.27	2.57 ± 0.15	2.75 ± 0.22
18:1n9	25.7 ± 1.50	22.4 ± 1.02	22.1 ± 1.10
20:1n9	0.20 ± 0.02	0.26 ± 0.06	0.48 ± 0.18
ΣMUFA	29.0 ± 2.28	25.3 ± 1.17	25.3 ± 0.99
18:2n6	11.1 ± 0.88	9.65 ± 0.32	10.9 ± 0.71
18:3n6	0.79 ± 0.06	0.77 ± 0.32	ND
20:2n6	1.11 ± 0.07	1.41 ± 0.07	1.33 ± 0.20
20:3n6	2.68 ± 0.72	1.85 ± 0.12	2.91 ± 1.00
20:4n6	5.23 ± 0.48	6.29 ± 0.41	5.95 ± 0.23
22:4n6	3.12 ± 0.44	4.66 ± 0.27	4.42 ± 0.37
22:5n6	4.02 ± 0.04	5.47 ± 0.32	5.05 ± 0.48
Σn6	28.0 ± 3.01	30.8 ± 1.12	31.6 ± 0.86
18:3n3	1.07 ± 0.21	1.19 ± 0.20	1.05 ± 0.13
20:5n3	0.31 ± 0.07	0.53 ± 0.08	0.39 ± 0.05
22:5n3	1.74 ± 0.38	2.27 ± 0.20	2.05 ± 0.23
22:6n3	5.84 ± 0.91^{a}	8.00 ± 0.69^{ab}	8.90 ± 0.59^{b}
Σn3	8.96 ± 0.68^{a}	12.0 ± 0.88^{ab}	12.62 ± 0.90^{b}
ΣPUFA	37.0 ± 2.29^{a}	42.8 ± 1.47^{ab}	46.5 ± 1.59^{b}
n3/n6	0.33 ± 0.04	0.36 ± 0.02	0.37 ± 0.02

Different letters indicate statistical differences (P&lt0.05) between strains (horizontal).
Not detected.
SFA, saturated fatty acid; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

In fish, the liver is considered to be an important secondary lipid depot organ (Sheridan 1994), and the FA content of lipid in the liver can decrease with growth (De Silva, Gunasekera & Austin 1997). This profile was evident in the strains and hybrid analysed here, and a sharp decrease was found when the body mass increased from 100 to 250 g, at the same time that muscle lipid also decreased. Considering the role of liver as a lipid depot organ, the decrease in lipid content accompanying growth reflects the use of this energetic substrate in growing animals and also indicates that the amount of crude lipid in the diet is adequate and prevents lipid accumulation in the liver, one indicator of excess dietary lipids (Sargent, Tocher & Bell 2002).

FAs

Analysis of FAs in the plankton is important because the animals use plankton to balance the commercial diet even when grown in cages and fed with a diet that fulfils their nutritional requirements (Alceste 2004; Gomes, Correia & Moreira 2010). According to Popma and Lovshin (1996), in the setting of a balanced diet, 30–50% of fish growth occurs due to the feeding on natural organisms from the environment. The results showed that the freshwater organisms analysed in the water samples were rich in C18 PUFA, corresponding to around 22% of the total FAs in the water, and the percentage of LC-PUFA was approximately 5%.

The FA profile in the diet presented equal percentages of SFA, MUFA and PUFA; however, in the latter, the percentage of C18:2n6 corresponds to almost 90% of total PUFA. C18:2n6 (linoleic acid) is mainly found in seeds such as soybean, sunflower and corn (Matsushita, Justi, Padre, Milinsk, Ayashi, Gomes, Visentainer & Souza 2006), suggesting a high inclusion of these items in the commercial diet utilized. This suggests that the 32% of crude protein present in the diet originated from a vegetable source (e.g., soybean)

Table 10 Fatty acid profiles of the total lipids in the skin of *Oreochromis niloticus*, Red-Stirling, hybrid and Chitralada (mean ± SEM)

	Skin		
Fatty acid (%)	**Red-Stirling**	**Hybrid**	**Chitralada**
14:0	2.29 ± 0.13^{a}	1.98 ± 0.09^{ab}	1.64 ± 0.30^{b}
15:0	0.24 ± 0.02	0.19 ± 0.01	0.19 ± 0.01
16:0	22.8 ± 0.72	22.3 ± 0.48	20.4 ± 0.98
17:0	0.48 ± 0.02	0.44 ± 0.01	0.41 ± 0.02
18:0	10.3 ± 1.63	7.38 ± 0.12	8.23 ± 0.74
20:0	1.33 ± 0.38	1.58 ± 0.13	1.53 ± 0.42
ΣSFA	37.5 ± 4.22^{a}	33.9 ± 0.97^{ab}	32.4 ± 3.10^{b}
16:1n7	3.87 ± 0.09	4.17 ± 0.17	4.34 ± 0.40
17:1n9	0.46 ± 0.09	0.40 ± 0.01	0.42 ± 0.03
18:1n9	31.6 ± 1.53	33.5 ± 0.32	31.3 ± 0.97
20:1n9	0.75 ± 0.27	0.24 ± 0.02	0.49 ± 0.25
ΣMUFA	36.8 ± 1.28	38.3 ± 0.52	36.8 ± 0.53
18:2n6	15.9 ± 0.42	14.7 ± 0.09	16.3 ± 0.52
18:3n6	0.98 ± 0.12	0.99 ± 0.03	0.95 ± 0.03
20:2n6	0.82 ± 0.03	0.86 ± 0.01	1.04 ± 0.03
20:3n6	0.71 ± 0.08	0.85 ± 0.11	1.02 ± 0.20
20:4n6	1.41 ± 0.16^{a}	3.37 ± 0.42^{ab}	3.70 ± 0.63^{b}
22:2n6	0.15 ± 0.02^{a}	0.22 ± 0.03^{ab}	0.27 ± 0.01^{b}
22:4n6	0.74 ± 0.08^{a}	1.28 ± 0.09^{ab}	1.52 ± 0.22^{b}
22:5n6	0.62 ± 0.09^{a}	1.63 ± 0.24^{ab}	1.85 ± 0.32^{b}
Σn6	21.3 ± 0.61^{a}	23.9 ± 0.70^{ab}	26.6 ± 0.89^{b}
18:3n3	2.23 ± 0.21	1.39 ± 0.09	1.44 ± 0.05
18:4n3	0.23 ± 0.03	ND	ND
20:3n3	0.25 ± 0.01^{a}	0.19 ± 0.02^{b}	ND
22:5n3	1.19 ± 0.13	0.50 ± 0.13	0.6 ± 0.09
22:6n3	0.26 ± 0.01^{a}	1.04 ± 0.14^{ab}	1.72 ± 0.16^{b}
Σn3	4.16 ± 0.38	3.12 ± 0.30	4.05 ± 0.34
ΣPUFA	25.5 ± 0.92^{a}	27.0 ± 0.99^{ab}	30.6 ± 1.22^{b}
n3/n6	0.19 ± 0.01	0.16 ± 0.01	0.15 ± 0.01

Different letters indicate statistical differences ($P < 0.05$) between strains (horizontal).

Not detected.

SFA, saturated fatty acid; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

with a low proportional inclusion of fishmeal, considering the low percentage of C20:5n3 (0.09%) and C22:6n3 (0.32%), the main FA found in fish meal.

Linoleic acid is essential to most freshwater fish and humans and is the main precursor of C20:4n6 (arachidonic acid), important in growth, reproduction, immune response modulation and physiological alterations in fish physiology due to environmental stress conditions (Bell, Tocher, Macdonald & Sargent 1995). C20:4n6 was not detected in either the water or the diet, but was present in all samples analysed (mainly in the polar fraction of liver FA). This suggests that these animals are elongating and/or desaturating C18 FAs to LC-PUFA and HUFA (Henderson & Tocher 1987), which are important in neural development and are also precursors of prostaglandins and leukotrienes (Youdim, Martin & Joseph 2000; Uauy, Hoffman, Peirano, Birch & Birch 2001). Like all vertebrates, fish do not have the desaturase enzymes Δ12 and Δ15 necessary to synthesize C18:2n6 and C18:3n3 respectively; hence, these essential FAs must be included in the fish diet.

The FA metabolism of many fish species in fish farms from temperate regions has been studied, and the results show that the elongation and desaturation of PUFA in hepatocytes, accessed by the Δ5 enzyme gene expression, increase when their diets are rich in C18 essential PUFA, exemplified by diets enriched with vegetable oils (Hastings, Agaba, Tocher, Leaver, Dick & Sargent 2001; Zheng, Tocher, Dickson, Bell & Teale 2004; Agaba, Tocher, Zheng, Dickson, Dick & Teale 2005; Tocher, Dick, Macglaughlin & Bell 2006). In contrast, when the animals are fed with diets rich in C20 and C22 PUFA, there is a decrease in the expression of the Δ5 gene (Hastings *et al.* 2001; Tocher, Bell, Dick & Crampton 2003; Zheng *et al.* 2004; Agaba *et al.* 2005; Tocher *et al.* 2006). This profile shows the role of C20–C22 PUFA as inhibitors of these enzymes (Tocher *et al.* 2006). However, for tropical species, this kind of research is rare. The data from this study showed that the animals from different strains equally desaturate C18:2n6 to C18:3n6 in the liver; however, in the further step in the FA synthetic pathway, the C20:4n6/C18:3n6 ratio is higher in hybrids when compared with Chitralada, evidencing that not only the diet but also the genetic background influences the activity of Δ5.

Luzia *et al.* (2003) analysed the FA profile of five important fish species in Brazil in the wild including 500 g *O. niloticus*. The data on the FA profiles of these wild animals are different from those of the animals reared in cages in our study. Primarily, the n3 and n6 PUFA are higher in the muscle of the strains and crossbred fish analysed herein than in wild tilapia (n3 was 7% and n6, 9%). These data corroborate what was established by Henderson and Sargent (1985); captive fish eating commercial diets have a higher percent of n6PUFA than do fish in the wild due to the extensive use of soybean and corn in the diets, as discussed previously.

The influence of genetic background on FA composition was analysed in the fillet, liver, adipose tissue, plasma and skin. In the muscle, the results showed that the genetic differences found between the Red-Stirling and Chitralada strains as well as their hybrid show no influence on the FA profile in the neutral or

the polar fraction of this tissue. Despite an alteration in the percentage of C18:0 and C16:1 in the neutral fraction, the sum of SFA and MUFA was unchanged. Garduño-Lugo *et al.* (2007) also did not find any difference in the FA composition of fillets when comparing wild Nile tilapia and a Red hybrid (Florida red tilapia × red *O. niloticus*).

On the other hand, the liver FA profile was found to be different among the strains and their hybrid. The analyses of the data showed that despite having the same concentration of lipids (at 500 g), Chitralada accumulate a higher percentage of PUFA in the liver; almost all n6PUFA are higher in the neutral fraction of the liver in this strain compared with Red-Stirling and hybrids, but the main difference is due to C18:2n6. This increase in n6PUFA percentage is compensated by a decrease in the percentage of SFA, mainly C18:0. In the liver polar fraction, the same increase in PUFA is found in Chitralada compared with Red-Stirling, but here the increase is due to C22:6n3, a n3PUFA. This difference in C22:6n3 was inherited by the hybrid, suggesting a FA profile in the polar fraction of the liver lipids similar to that of the Chitralada.

The FA profile of the adipose tissue was also affected by the strain. Chitralada accumulate a higher percentage of MUFA, mainly C18:1, and accumulate a lower percentage of SFA, mainly C18:0. Considering the role of plasma in the transport of these FAs, this pattern can explain the previously discussed FA profiles in the skin.

The FA analyses of the skin were considered to be important because the fillets are frequently commercialized with the skin. Also, the skin has been viewed as a source of bad fat by the general population because of comparisons with chicken products that are rich in SFA and poor in PUFA (Ferreira, Braga, Souza, Campos & Vieira 1999). Independent of the tilapia strain analysed, a high percentage of PUFA was obtained in tilapia skin (26–30%), with a predominance of C18:2n6 and considerable amounts of n3PUFA. Chitralada skin presented higher percentages of most C20–C22 n6PUFA when compared with Red-Stirling, and the same pattern was found for the LCPUFA C22:6n3, evidenced by the higher percentage of C22:6n3 in the plasma of Chitralada. This suggests that the consumption of tilapia fillet with the skin is a healthy practice, particularly the Chitralada. Additionally, Chitralada skin had a lower percentage of SFA, important in the prevention of cardiovascular diseases (Simopoulos 1991; Howe 1997; Wahlquist 1998). The hybrid profile had intermediate values between both parental species.

The similarities between the FA profiles of all tissues suggest that the fillets of the strains and hybrid analysed present no alterations in the biochemical composition at commercial size and this result can be attributed to the lean characteristic of tilapia fillet, which was not altered by different genetic backgrounds. However, the metabolism of the animals differs among the three groups. The data suggest that Chitralada have a FA profile that is qualitatively different, even though the Red-Stirling and hybrid have the same amount of hepatic lipids. Specifically, Chitralada have a higher percentage of n6PUFA stored in the hepatocytes and a higher percentage of C22:6n3 in the hepatocyte membranes, which is clearly reflected in the skin. This pattern suggests that even consuming the same diet, Chitralada have a higher ability to depot PUFA in the skin due to alterations observed in the liver synthetic pathway.

A growth performance trial comparing these strains with the same animals used in the present study confirmed that Chitralada reach a higher body mass than Red-Stirling over the same period even when eating the same diet. In contrast, the hybrid's body mass was between the two strains, suggesting a possible gene interaction between the parental species (Freitas 2007). Studies of the biochemical composition of fish tissues show that the heritability of lipid traits is higher than that of protein traits (Quinton, Mcmillan & Glebe 2005; Tobin, Kause, Mäntysaari, Martin, Houlihan, Dobly, Kiessling, Rungruangsaktorrissen, Ritola & Ruohonen 2006; Kocour, Mauger, Rodina, Gela, Linhart & Vandeputte 2007), and Tobin *et al.* (2006) suggest that rapid growth in trout is related to increased fat deposition. In conclusion, we suggest that the fat content, and mainly, the FA profile of the stored fat, is important to modulate fish growth.

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References

Agaba M.K., Tocher D.R., Zheng X., Dickson C.A., Dick J.R. & Teale A.J. (2005) Cloning and functional characterization

of polyunsaturated fatty acid elongases of marine and freshwater teleost fish. *Comparative and Biochemistry Physiology* **142B**, 342–352.

Alceste C.C. (2004) Alternative protein sources in Tilapia feed formulation. *Aquaculture Magazine* **98**, 56–60.

Bell J.G., Tocher D.R., Macdonald F.M. & Sargent J.R. (1995) Effects of dietary borage oil [enriched in *y*-linolenic acid, 18: 3 (n-6)] or marine fish oil [enriched in eicosaoentaenoic acid, 20: 5 (n-3)] on growth, mortalities, liver histopathology and lipid composition of juvenile turbot (*Scophthalmus maximus*). *Fish Physiology and Biochemistry* **14**, 373–383.

Bentsen H.B., Eknath A.E., Palada de Vera M.S., Danting J.C., Bolivar H.L., Reyes R.A., Dionisio E.E., Longalong F.M., Circa A.V., Tayamen M.M. & Gjerde B. (1998) Genetic improvement of farmed tilapias: growth performance in a complete diallyl cross experiment with eight strains of *Oreochromis niloticus*. *Aquaculture* **160**, 145–173.

Beveridge M.C.M. & McAndrew B.J. (eds) (2000) *Tilapias: Biology and Exploitation. Fish and Fisheries Series 25*. Kluwer Academic Publishers, Dordrecht, the Netherlands, 505pp.

Christie W.W. (2003) *Lipids Analysis*, 3rd edn. The Oily Press, Bridgwater, UK, 416pp.

Clement S. & Lovell R.T. (1994) Comparison of processing yield and nutrient composition of cultured Nile tilapia (*Oreochromis niloticus*) and channel catfish (*Ictalurus punctatus*). *Aquaculture* **119**, 299–310.

Colquhoun A., Miyake J.A. & Benadiba M. (2009) Fatty acids, eicosanoids and cancer. *Nutrition Therapy & Metabolism* **27**, 105–112.

De Silva S.S., Gunasekera R.M. & Austin C.M. (1997) Changes in the fatty acid profiles of hybrid red tilapia, *Oreochromis mossambicus* X *Oreochromis niloticus*, subjected to short-term starvation, and a comparison with changes in seawater raised fish. *Aquaculture* **153**, 273–290.

EL-Dahhar A. (1997) *Effect of fish size on growth performance, body composition and feed utilization of Nile tilapia in Egypt*. In: *World Aquaculture* 97, p.134. Seattle, WA, USA

Ferreira J.M., Braga M.S., Sousa R.V., Campos E.J. & Vieira E.C. (1999) Composição em ácidos graxos da gordura na carcaça de frangos de corte sob dietas com diferentes fontes de energia. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia* **51**, 201–206.

Folch J., Less M. & Sloane Stanley G.H. (1957) A simple method for the isolation and purification of total lipids from animal tissues. *The Journal of Biological Chemistry* **226**, 497–503.

Food and Agriculture Organization. (2006) *Review of the Current State of World Aquaculture Insurance. Fisheries Technical Paper, no. 493*. FAO, Rome, Italy, 92pp. Available at http://www.fao.org.br (accessed 22 February 2008)..

Freitas J.R. (2007). *Avaliação de desempenho e de coloração de híbridos intraespecíficos de Oreochromis niloticus, das variedades Red Stirling e Chitralada*. Dissertação de Mestrado em Biotecnologia, Universidade de Mogi das Cruzes, SP, Brazil, 123pp.

Frings C.S., Fendly T., Dunn R.T. & Quenn C.A. (1972) Improved determination of total lipids by the sulpho-phospho-vanilin reaction. *Clinical Chemistry* **18**, 673–674.

Garduño-Lugo M., Granados-Alvarez I., Olvera-Novoa M.A. & Muñoz-Córdova G. (2003) Comparison of growth, fillet yield and proximate composition between Stirling Nile tilapia (wild type) (*Oreochromis niloticus*, Linnaeus) and red hybrid tilapia (Florida red tilapia X Stirling red *O. niloticus*) males. *Aquaculture Research* **34**, 1023–1028.

Garduño-Lugo M., Herrera-Solis J.R., Ângulo-Guerrero J.O., Muñoz-Cordóva G. & Cruz-Medina J. (2007) Nutrient composition and sensory evaluation of fillets from wild-type Nile tilapia (*Oreochromis niloticus*, Linnaeus) and a red hybrid (Florida red tilapia x red *O. niloticus*). *Aquaculture Research* **38**, 1074–1081.

Gomes A.D., Correia T.G. & Moreira R.G. (2010) Fatty acids as trophic biomarkers in vitellogenic females in an impounded tropical river. *Fish Physiology and Biochemistry* **36**, 699–718.

Hastings N., Agaba M., Tocher D.R., Leaver M.J., Dick J.R. & Sargent J.R. (2001) A vertebrate fatty acid desaturase with delta 5 and delta 6 activities. *Proceedings of the National Academy of Sciences USA* **98**, 14304–14309.

Henderson R.J. & Sargent J.R. (1985) Fatty acid metabolism in fish. In *Nutrition and feeding of fish* (ed by C.B. Cowey, A.M. Mackie & J.G. Bell), pp 349–364. Academic Press, London, UK.

Henderson R.J. & Tocher D.R. (1987) The lipid composition and biochemistry of freshwater fish. *Progress in Lipid Research* **26**, 281–347.

Howe P.R.C. (1997) Dietary fats and hypertension: focus on fish oil. *Annals of the New York Academy of Sciences* **827**, 339–352.

Instituto Adolfo Lutz (1985) Normas analíticas do Instituto Adolfo Lutz v. 1. In *Métodos Químicos e Físicos para zAnálise de Alimentos*, 3 edn (ed. by W. Pregnolatto & N.S. Pacuet), pp. 27–28. IMESP, São Paulo, Brazil.

Justi K.C., Hayashi C., Visentainer J.V., Souza N.E. & Matsushita M. (2003) The influence of feed supply time on the fatty acids profile of Nile tilapia (*Oreochromis niloticus*) fed on the diet enriched with n-3 fatty acid. *Food Chemistry* **80**, 489–493.

Kocour M., Mauger S., Rodina M., Gela D., Linhart O. & Vandeputte M. (2007) Heritability estimates for processing and quality traits in common carp (*Cyprinius carpio* L.) using a molecular pedigree. *Aquaculture* **270**, 43–50.

Krishna Mohan I. & Das U.M. (2001) Prevention of chemically induced diabetes mellitus in experimental animals by polyunsaturated fatty acids. *Nutrition* **17**, 126–151.

Lowry O.H., Rosenbrough N.J., Farr A.L. & Randall R.J. (1951) Protein measurement with the Folin phenol reagent. *The Journal of Biological Chemistry* **193**, 265–275.

Luzia L.A., Sampaio G.R., Castelucci C.M.W. & Torres E.A.F.S. (2003) The influence of season on the lipid profiles of five commercially important species of Brazilian Fish. *Food Chemistry* **83**, 93–97.

Matsushita M., Justi K.C., Padre R.G., Milinsk M.C., Ayashi C., Gomes S.T.M., Visentainer J.V. & Souza N.E. (2006) Influence of diets enriched with different vegetable oils on the performance and fatty acid profile of Nile tilapia (*Oreochromis niloticus*) fingerlings. *Acta Scientiarum. Technology* **28**, 125–131.

Milligan C.L. & Girard S.S. (1993) Lactate metabolism in rainbow trout. *Journal of Experimental Biology* **180**, 175–193.

Moreira A.A., Moreira H.L.M. & Hilsdorf A.W.S. (2005) Comparative growth performance of two Nile tilapia (Chitralada and Red-Stirling), their crosses and the Israeli tetra hybrid ND-56. *Aquaculture Research* **36**, 1049–1055.

Moreira A.A., Silva J.V., Souza V.R. & Hilsdorf A.W.S. (2007) Variabilidade genética de duas variedades de tilápia nilótica por meio de marcadores microssatélites. *Pesquisa Agropecuária Brasileira* **42**, 521–526.

Parrish C.C. (1999) Dissolved and particulate marine classes: a review. *Marine Chemistry* **23**, 17–40.

Popma T.J. & Lovshin L. (1996) *Worldwide prospects for commercial production of tilápia.* Research and Development **41**, 23pp, International Center for Aquaculture and Aquatic Environments, Auburn University, Auburn, AL.

Pádua D.M.C. (1996) *Utilização da levedura alcoólica (Saccharomyces cerevisae) como fonte protéica na alimentação de juvenis de Pacu (Piaractus mesopotamicus, PISCES, TELEOSTEI): Aspectos metabólicos e de desempenho produtivo.* Dissertação de Mestrado, Universidade Estadual Paulista, Jaboticabal, SP, Brazil, 120pp.

Quinton C.D., McMillan I. & Glebe B.D. (2005) Development of an Atlantic salmon (*Salmo salar*) genetic improvement program: genetic parameters of harvest body weigth and carcass quality traits estimated with animal models. *Aquaculture* **247**, 211–217.

Rasoarahona J.R.E., Barnathan G., Bianchini J.P. & Gaydou E.M. (2005) Influence of season on the lipid content and fatty acid profiles of three tilapia species (*Oreochromis niloticus, O. macrovir and Tilapia rendalli*) from Madagascar. *Food Chemistry* **91**, 683–694.

Sargent J.R., Tocher D.R. & Bell J.G. (2002) The lipids. In *Fish Nutrition* (ed. by J.E. Halver & R.W. Hardy), pp 181–257. Academic Press, Elsevier, San Diego, CA, USA.

Shearer D.K. (1994) Factors affecting the proximate composition of cultured fishes with emphasis on salmonids. *Aquaculture* **119**, 63–88.

Sheridan M.A. (1994) Regulation of lipid metabolism in poikilothermic vertebrates. *Comparative Biochemistry and Physiology* **107B**, 495–508.

Simopoulos A.P. (1991) Omega-3 fatty acids in health and disease and in growth and development. *American Journal of Clinical Nutrition* **54**, 438–463.

Tobin D., Kause A., Mäntysaari E.A., Martin S.A.M, Houlihan D.F., Dobly A., Kiessling A., Rungruangsak-Torrissen K., Ritola O. & Ruohonen K. (2006) Fat or lean? The quantitative genetic basis for selection strategies of muscle and body composition traits in breeding schemes of rainbow trout (*Oncorhynchus mykiss*). *Aquaculture* **261**, 510–521.

Tocher D.R., Bell J.G., Dick J.R. & Crampton V.O. (2003) Effects of dietary vegetable oil on A*tlantic salmon* hepatocyte fatty acid desaturation and liver fatty acid compositions. *Lipids* **38**, 723–732.

Tocher D.R., Dick J.R., Macglaughlin P. & Bell J.G. (2006) Effect of diets enriched in Δ6 desaturated fatty acids (18: 3*n*-6 and 18: 4*n*-3), on growth, fatty acid composition and highly unsaturated fatty acid synthesis in two populations of Artic charr (*Salvelinus alpinus* L.). *Comparative Biochemistry and Physiology* **144**, 245–253.

Uauy R., Hoffman D.R., Peirano P., Birch D.G. & Birch E.E. (2001) Essential fatty acids in visual and brain development. *Lipids* **36**, 885–895.

Wahlquist M.L. (1998) Nutritional pathways to coronary heart disease. *Atherosclerosis* **136**, S28.

Yang Z. (1995) *Development of a gas chromatographic method for profiling neutral lipids in marine samples.* MSc thesis, Memorial University of Newfoundland St John's, Newfoundland, 96pp.

Youdim K.A., Martin A. & Joseph J.A. (2000) Essential fatty acids and the brain: possible health implications. *International Journal of Developmental Neuroscience* **18**, 383–399.

Zheng X., Tocher D.R., Dickson C.A., Bell J.G. & Teale A.J. (2004) Effects of diets containing vegetable oil on expression of genes involved in highly unsaturated fatty acids biosynthesis in liver of Atlantic salmon (*Salmo salar*). *Aquaculture* **236**, 467–483.

