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Effects of Fasting on Fatty Acid Composition of Muscle, Liver, and Abdominal Fat in Channel Catfish *Ictalurus punctatus*

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Abstract

Channel catfish *Ictalurus punctatus* were fasted for 20, 40, 60, and 80 d. Proximate and fatty acid composition of liver, abdominal fat, muscle, and viscera were determined. Percentage moisture, protein, and lipid of viscera showed little change during the period of fasting. Percentage protein in muscle decreased ($P < 0.05$) after 20 d of fasting from time 0 (control), while percentage lipid increased ($P < 0.05$). Fish fasted for 0, 40, 60, and 80 d were not different ($P > 0.05$). In the liver, percentage lipid was higher in fish that were not fasted (0 d) than in fish fasted 20, 40, 60, and 80 d ($P < 0.05$), while percentage moisture was lower in control fish compared to all other treatments ($P < 0.05$). Fatty acid composition of muscle and liver indicated that docosahexaenoic acid (DHA), 22:6(n-3), was conserved in these tissues during fasting, while oleic acid, 18:1(n-9), concentration decreased during fasting. Fatty acid composition of abdominal fat indicated that a high percentage (>50%) of the total lipid was composed of oleic acid and there was little change in levels of individual fatty acids in abdominal fat during 80 d of fasting.

There are conflicting data regarding which fatty acids are essential for channel catfish growth. Stickney et al. (1983) reported that a linolenic acid, 18:3(n-3), level of 1%, reduced growth of channel catfish *Ictalurus punctatus* compared to fish fed diets with <1% linolenic acid. Satoh et al. (1989a, 1989b) reported in a later study that channel catfish required 1–2% linolenic acid in the diet. Greater weight gain has been observed in channel catfish fed diets containing 2.0–2.5% linoleic acid, 18:2(n-6), than in fish fed a fat-free diet or diets with higher percentages of linoleic acid (Stickney et al. 1984). Channel catfish fed diets supplemented with marine fish oil that contained a high percentage of eicosapentaenoic acid (EPA), 20:5(n-3), or docosahexaenoic acid (DHA), 22:6(n-3), had higher growth rates than fish fed diets containing less EPA or DHA (Yingst and Stickney 1979; Santha and Gatlin 1991).

The effect of fasting on the fatty acid composition of fish may indicate the utilization of particular fatty acids in tissues (Koven et al. 1989). The purpose of this study was to determine the fatty acid composition of liver, muscle, and abdominal fat from fasted channel catfish and compare conservation and utilization patterns of selected fatty acids.

Materials and Methods

Experimental Animals and Conditions

Twenty channel catfish (mean weight 546 ± 30 g) were seined from a 0.04 ha pond at the Aquaculture Research Center, Kentucky State University, and placed in groups of four into five outdoor 1,112 L circular tanks (1.5 m diameter). Fish had been fed a commercial diet (Delta Western, Indianola, Mississippi) for 3 wk prior to collection. Fish had not been fed 24 h prior to harvest. Individual weights of fish were not recorded. Water was supplied to each tank from a plastic-lined pond at a rate of 3 L/min. The pond contained only phytoplankton and zooplankton as potential nutrient sources. Continuous aeration was provided by an airstone connected to an air

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blower. A net (2.0 mm mesh size) was placed over the top of each tank to prevent fish from jumping out and to reduce sunlight intensity. Dissolved oxygen and temperature were measured daily (0830 h) with a YSI Model 57 oxygen meter. Ammonia and nitrite were measured weekly with a DREL/5 spectrophotometer (Hach, Inc., Loveland, Colorado) and pH was measured weekly using an electronic pH meter (Accumet 900, Fisher Scientific, Cincinnati, Ohio). All water quality parameters were within accepted values for channel catfish (Boyd 1979). Average water quality parameters (±SE) were: dissolved oxygen, 6.8 ± 0.5 mg/L; temperature, 25.0 ± 0.3 C; total ammonia nitrogen, 0.2 ± 0.05 mg/L; nitrite, 0.1 ± 0.1 mg/L; pH, 8.0 ± 0.2.

At day 0 and every 20 d thereafter until day 80, 4 fish from a single tank were killed by a sharp blow to the head, and liver, abdominal fat, and muscle were dissected from each fish. Two samples of each tissue, approximately 15 g, were flash-frozen in liquid nitrogen (−196 C), placed in glass vials with teflon-lined screw-top caps, and stored under nitrogen for subsequent lipid extraction. Muscle tissue was always obtained from the area 2–4 cm anterior to the caudle peduncle. One sample of liver, muscle, and viscera (minus liver and abdominal fat) was analyzed for protein, lipid, and moisture. Protein was measured by macro-Kjeldahl, total lipid was measured by ether extraction, and moisture was measured by drying (95 C) to constant weight in a convection oven (AOAC 1990).

Fatty Acid Analysis

Lipid was extracted from the other 15 g tissue sample with chloroform-methanol by the method of Bligh and Dyer (1959) as modified by Kates (1986). Fatty acid methyl esters were obtained according to the method of AOAC (1990) and analyzed using a Hewlett-Packard 5890 II gas chromatograph equipped with an Omegawax 320 30 m fused silica capillary column (Supelco, Inc., Bellefonte, Pennsylvania) and a flame-ionization detector. The carrier gas was helium. Oven temperature was programmed from 160 to 220 C at a rate of 2 C/min and then from 220 to 270 C at a rate of 10 C/min. Detector response was recorded and quantitated with an electronic integrator-recorder. An internal standard (24:0) was added and fatty acid methyl esters were identified by comparison of their retention times with those of authentic standards (Nu-Chek Prep, Elysian, Minnesota).

Statistical Analysis

Data were analyzed by ANOVA to determine if differences in fatty acid composition of tissues occurred due to fasting (Statistical Analysis Systems 1988). Duncan's multiple range test was used to determine where differences existed among means. All data were transformed to arcsine values prior to analysis (Zar 1984). Means are reported as untransformed data to facilitate comparison with similar studies.

Results

Proximate Analysis

Percentage protein in viscera did not differ ($P > 0.05$) among treatments and averaged 11.4% on a wet-weight basis (Table 1). Highest lipid levels among tissues were found in viscera, although no difference ($P > 0.05$) in lipid content of viscera occurred during 80 d of fasting (averaging 20.6% lipid). Percentage moisture in viscera was lower ($P < 0.05$) in fish at day 0 (60.1%) than in fish fasted for 40 d (74.1%), but did not differ ($P > 0.05$) from moisture content of fish fasted 20, 60, and 80 d.

Percentage protein in muscle of fish fasted 20 d (17.6%) was lower ($P < 0.05$) than protein in muscle of fish fasted 0, 40, 60, and 80 d (Table 1). The percentage lipid in fish fasted 20 d (4.1%) was higher ($P < 0.05$) than that in fish fasted 0, 40, 60, and 80 d (2.1, 1.8, 1.1, and 1.3%, respectively). Percentage moisture in muscle was significantly lower ($P < 0.05$) in fish fasted for 20 d (75.2%) than in fish fasted 0, 40, 60, and 80 d.

TABLE 1. *Percentage (wet-weight basis) protein, lipid, and moisture of viscera, muscle, and liver from channel catfish starved for various periods of time (0, 20, 40, 60, and 80 d). Values are means ± SE of four replications. Means in the same column, for each tissue, with different superscripts were significantly different (P < 0.05).*

Days starved	% protein	% lipid	% moisture
		Viscera	
0	12.50 ± 0.59[a]	25.71 ± 3.38[a]	60.13 ± 2.42[b]
20	10.62 ± 0.80[a]	17.61 ± 5.40[a]	67.36 ± 6.13[ab]
40	10.73 ± 1.75[a]	15.10 ± 3.08[a]	74.13 ± 1.77[a]
60	12.28 ± 0.79[a]	26.44 ± 3.40[a]	64.06 ± 2.70[ab]
80	10.86 ± 0.36[a]	17.95 ± 1.86[a]	65.83 ± 3.64[ab]
		Muscle	
0	19.40 ± 0.42[a]	2.13 ± 0.57[b]	77.48 ± 0.57[a]
20	17.61 ± 0.27[b]	4.07 ± 0.86[a]	75.21 ± 0.75[b]
40	18.90 ± 0.19[a]	1.78 ± 0.57[b]	78.47 ± 0.48[a]
60	18.56 ± 0.28[a]	1.12 ± 0.27[b]	78.11 ± 0.35[a]
80	18.82 ± 0.15[a]	1.29 ± 0.37[b]	78.83 ± 0.29[a]
		Liver	
0	13.77 ± 0.74[b]	6.90 ± 3.04[a]	69.82 ± 2.72[b]
20	16.23 ± 0.47[a]	1.85 ± 0.41[b]	77.33 ± 0.83[a]
40	16.39 ± 2.92[a]	2.95 ± 1.16[b]	74.86 ± 2.92[ab]
60	16.16 ± 0.10[a]	2.08 ± 0.56[b]	76.93 ± 0.79[a]
80	13.77 ± 0.56[b]	1.23 ± 0.14[b]	76.18 ± 0.56[a]

Percentage protein in liver of fish fasted for 20, 40, and 60 d was higher ($P < 0.05$) than in fish at day 0 and fish fasted for 80 d (Table 1). Percentage lipid in liver was higher ($P < 0.05$) in fish at day 0 (6.9%) than in fish fasted 20, 40, 60, and 80 d. The decrease in the percentage of liver lipid in fasted fish was associated with an increase in the percentage of liver moisture. Fish at day 0 had a lower level (69.8%) of liver

TABLE 2. *Percentage of individual fatty acids (area %) in abdominal fat of channel catfish starved for 0, 20, 40, 60, and 80 d. Values are means ± SE of four replications. Means in the same row with different superscripts are significantly different (P < 0.05).*

	Days starved				
Fatty acid	0	20	40	60	80
16:0	15.99 ± 0.32[a]	16.92 ± 0.31[a]	15.63 ± 0.82[a]	15.81 ± 0.60[a]	16.35 ± 0.33[a]
16:1(n-7)	2.81 ± 0.08[a]	3.19 ± 0.15[a]	2.81 ± 0.31[a]	3.06 ± 0.11[a]	2.92 ± 0.09[a]
18:0	5.63 ± 0.24[ab]	5.74 ± 0.25[ab]	6.40 ± 0.39[a]	6.15 ± 0.13[ab]	5.47 ± 0.08[b]
18:1(n-9)	58.08 ± 0.44[a]	51.58 ± 1.50[b]	56.46 ± 2.02[a]	55.53 ± 0.85[ab]	55.28 ± 1.60[ab]
18:2(n-6)	9.43 ± 0.34[b]	12.63 ± 0.41[a]	10.41 ± 1.21[ab]	10.97 ± 0.69[ab]	10.40 ± 0.35[ab]
18:3(n-3)	1.06 ± 0.08[ab]	1.18 ± 0.09[a]	0.82 ± 0.09[b]	0.92 ± 0.01[ab]	0.97 ± 0.18[ab]
20:1(n-9)	1.66 ± 0.13[a]	1.71 ± 0.00[a]	1.70 ± 0.06[a]	1.70 ± 0.15[a]	1.88 ± 0.12[a]
20:2(n-6)	0.68 ± 0.05[a]	0.69 ± 0.01[a]	0.72 ± 0.05[a]	0.71 ± 0.03[a]	0.79 ± 0.06[a]
20:3(n-6/n-9)	0.65 ± 0.02[a]	0.67 ± 0.03[a]	0.63 ± 0.05[a]	0.65 ± 0.01[a]	0.67 ± 0.05[a]
20:4(n-6)	0.27 ± 0.03[a]	0.28 ± 0.02[a]	0.24 ± 0.03[a]	0.25 ± 0.01[a]	0.29 ± 0.06[a]
20:5(n-3)	0.16 ± 0.02[a]	0.35 ± 0.12[a]	0.18 ± 0.10[a]	0.18 ± 0.02[a]	0.19 ± 0.10[a]
22:5(n-3)	0.32 ± 0.01[a]	0.38 ± 0.05[a]	0.25 ± 0.09[a]	0.30 ± 0.02[a]	0.33 ± 0.08[a]
22:6(n-3)	0.31 ± 0.03[a]	0.33 ± 0.09[a]	0.19 ± 0.07[a]	0.17 ± 0.02[a]	0.31 ± 0.05[a]
Other[1]	2.95	4.35	3.56	3.60	4.15

[1] Other fatty acids include: 8:0, 10:0, 11:0, 12:0, 13:0, 14:0, 14:1(n-5), 15:0, 15:1(n-5), 17:0, 17:1(n-7), 18:4(n-3), 20:3(n-3), 22:0, 22:1(n-9), 22:2(n-6), 22:4(n-6), 22:5(n-6), 24:0, 24:1(n-9), and unidentified fatty acids.

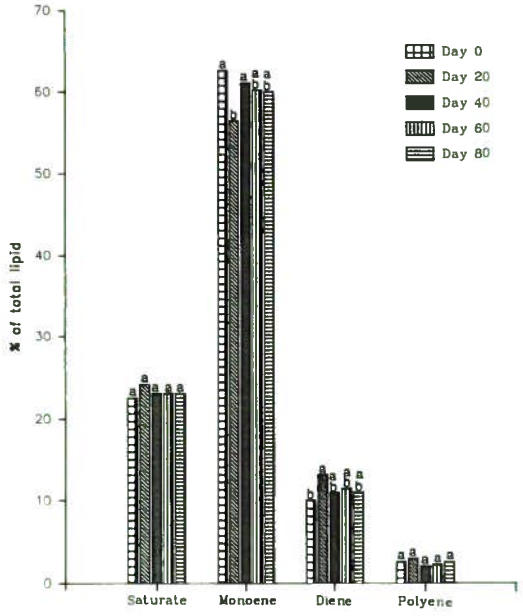

FIGURE 1. *Percentage of saturated, monoenoic, dienoic, and polyenoic fatty acids of abdominal fat from channel catfish starved for 0, 20, 40, 60, and 80 d. Bars within a lipid class with different letters were significantly different (P < 0.05).*

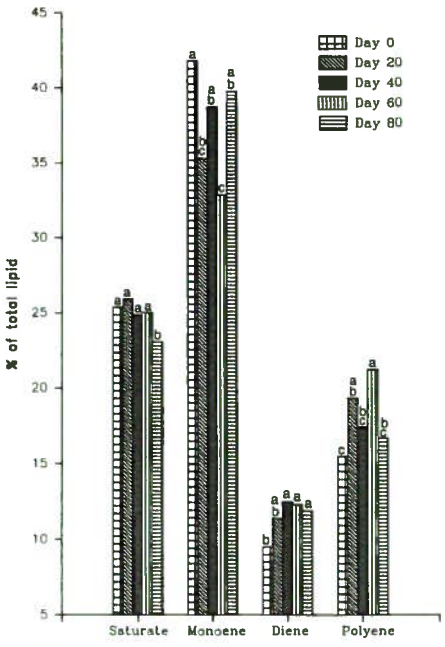

FIGURE 2. *Percentage of saturated, monoenoic, dienoic, and polyenoic fatty acids of muscle from channel catfish starved for 0, 20, 40, 60, and 80 d. Bars within a lipid class with different letters were significantly different (P < 0.05).*

moisture than fish fasted for 20 (77.3%), 60 (76.9%), and 80 (76.2%) d ($P < 0.05$).

Fatty Acid Composition

Abdominal fat. Fatty acid composition of abdominal fat, muscle, and liver showed marked differences in response to fasting. In the abdominal fat of fish at day 0, oleic acid, 18:1(n-9), was the predominant fatty acid (51–58%). Fatty acids such as palmitic acid, 16:0, octadecanoic acid, 18:0, and linoleic acid, 18:2(n-6), were present in moderate amounts (5–17%) (Table 2). The n-3 highly unsaturated fatty acids (HUFA) eicosapentaenoic acid (EPA), 20:5(n-3), and docosahexaenoic acid (DHA), 22:6(n-3), were present at very low levels (0.1–0.3%) of the total fatty acids. Little change occurred in the fatty acid composition of abdominal fat during 80 d of fasting. The majority (>80%) of lipid was composed of saturated and monoenoic fatty acids (Fig. 1).

Muscle. In muscle tissue, saturated fatty acids comprised approximately 25% of the total fatty acid fraction, with the percentage of saturated fatty acids of fish fasted for 80 d lower ($P < 0.05$) than levels in fish at day 0 and fasted for 20, 40, and 60 d (Fig. 2). The major saturated fatty acids were 16:0 and 18:0. There were lower ($P < 0.05$) percentages of these two fatty acids in fish fasted for 80 d (15.8 and 6.5%, respectively) compared to fish at all other sampling periods (Table 3).

Monoenoic fatty acids comprised 33–42% of the total fatty acid fraction. Levels of monoenoics in fish at day 0 and those fasted for 40 and 80 d did not differ ($P > 0.05$); however, fish fasted for 60 d had lower (32%) levels of monoenoics than fish at day 0 and fish fasted for 40 and 80 d. No difference ($P > 0.05$) was found between fish fasted for 20 d and fish fasted for 60 d. The major monoenoic fatty acid was oleic acid, 18:1(n-9). Fish fasted for 60 d had lower ($P < 0.05$) percentages of oleic acid (30.2%) than fish

TABLE 3. *Percentage of individual fatty acids (area %) in muscle of channel catfish starved for 0, 20, 40, 60, and 80 d. Values are means ± SE of four replications. Means in the same row with different superscripts are significantly different (P < 0.05).*

Fatty acid	Days starved				
	0	20	40	60	80
16:0	17.24 ± 0.46^{a}	17.13 ± 0.30^{a}	16.55 ± 0.50^{ab}	16.74 ± 0.11^{a}	15.83 ± 0.29^{b}
16:1(n-7)	2.22 ± 0.09^{a}	2.01 ± 0.05^{a}	0.20 ± 0.21^{ab}	1.79 ± 0.02^{b}	2.29 ± 0.14^{a}
18:0	7.49 ± 0.13^{a}	7.96 ± 0.15^{a}	7.33 ± 0.40^{a}	7.63 ± 0.12^{a}	6.48 ± 0.12^{b}
18:1(n-9)	38.32 ± 1.50^{a}	32.20 ± 1.04^{bc}	35.80 ± 0.79^{ab}	30.22 ± 0.39^{c}	36.17 ± 2.20^{ab}
18:2(n-6)	8.56 ± 0.33^{b}	10.41 ± 0.65^{a}	11.34 ± 0.79^{a}	11.26 ± 0.66^{a}	10.67 ± 0.53^{a}
18:3(n-3)	0.74 ± 0.03^{a}	0.75 ± 0.04^{a}	0.83 ± 0.06^{a}	0.94 ± 0.05^{a}	0.80 ± 0.10^{a}
20:1(n-9)	1.16 ± 0.09^{a}	1.04 ± 0.06^{a}	0.93 ± 0.24^{a}	0.89 ± 0.07^{a}	1.30 ± 0.08^{a}
20:2(n-6)	0.97 ± 0.09^{a}	0.99 ± 0.03^{a}	1.13 ± 0.12^{a}	1.04 ± 0.04^{a}	1.20 ± 0.12^{a}
20:3(n-6/n-9)	2.48 ± 0.21^{a}	2.48 ± 0.10^{a}	2.48 ± 0.19^{a}	2.99 ± 0.16^{a}	2.83 ± 0.18^{a}
20:4(n-6)	3.74 ± 0.27^{a}	4.55 ± 0.45^{a}	3.40 ± 0.26^{b}	4.55 ± 0.25^{a}	3.67 ± 0.34^{ab}
20:5(n-3)	1.18 ± 0.16^{a}	1.57 ± 0.26^{a}	1.24 ± 0.19^{a}	1.73 ± 0.23^{a}	1.05 ± 0.23^{a}
22:5(n-3)	2.53 ± 0.24^{b}	3.28 ± 0.19^{a}	3.17 ± 0.21^{a}	3.66 ± 0.17^{a}	2.98 ± 0.29^{ab}
22:6(n-3)	4.81 ± 0.22^{c}	6.71 ± 0.35^{ab}	6.30 ± 0.75^{bc}	7.35 ± 0.21^{a}	5.36 ± 0.72^{bc}
Other[1]	8.56	8.92	9.30	9.21	9.37

[1] Other fatty acids include: 8:0, 10:0, 11:0, 12:0, 13:0, 14:0, 14:1(n-5), 15:0, 15:1(n-5), 17:0, 17:1(n-7), 18:4(n-3), 20:3(n-3), 22:0, 22:1(n-9), 22:2(n-6), 22:4(n-6), 22:5(n-6), 24:0, 24:1(n-9), and unidentified fatty acids.

at day 0 and fasted for 40 and 80 d (Table 3).

Dienoic fatty acids comprised 9–13% of the total fatty acid fraction. Percentages of dienoic fatty acids were higher ($P < 0.05$) in fish fasted for 40, 60, and 80 d compared to fish at day 0. The major dienoic fatty acid was linoleic acid, 18:2(n-6). Fish at day 0 had lower percentages of linoleic acid (8.6%) than fish fasted for 20, 40, 60, and 80 d (Table 3).

Polyenoic fatty acids comprised 15–22% of the total fatty acid fraction. Percentages of polyenoic fatty acids in fish at day 0 and fish fasted for 40 and 80 d were lower ($P < 0.05$) than in fish fasted for 20 and 60 d (Fig. 2). The major polyenoic fatty acids were 22:5(n-3) and docosahexaenoic acid (DHA), 22:6(n-3). Fish at day 0 had lower ($P < 0.05$) percentages of 22:5(n-3) than in fish fasted for 20, 40, and 60 d, but not different ($P > 0.05$) than in fish fasted for 80 d. Percentage of DHA was higher in fish fasted for 20 and 60 d compared to fish at day 0; however, DHA level in fish at day 0 was not different ($P > 0.05$) compared to fish fasted 40 and 80 d (Table 3).

Liver. In liver, a significant increase in saturated fatty acids occurred after fish had been fasted for 20 d and were higher ($P < 0.05$) in fish fasted 40, 60, and 80 d than in day 0 fish (Fig. 3). This increase was due to higher ($P < 0.05$) percentages of 16:0 in fasted fish compared to fish at day 0 (Table 4).

Fish at day 0 had higher ($P < 0.05$) percentages of monoenoic fatty acids than in fish fasted 20, 40, 60 and 80 d. This was due to a dramatic decrease in the level of oleic acid in liver after 20 d of fasting (Table 4). Oleic acid comprised 56% of liver lipid at day 0, but only 32–37% of liver lipid after 20–80 d of fasting.

Dienoic fatty acids were higher ($P < 0.05$) in fish fasted 20, 40, 60, and 80 d than in fish at day 0 (Fig. 3). This was due to increases in the percentages of linoleic acid and eicosadienoic acid, 20:2(n-6) (Table 4). Fish fasted between 20–80 d had an average of 7.6% linoleic acid compared to 2.8% for unfasted fish ($P < 0.05$).

Polyenoic fatty acids in fish fasted 20, 40, 60, and 80 d were higher ($P < 0.05$) than in fish at day 0 (Fig. 3). This increase was due to increases in arachidonic acid, 20:4(n-6). EPA, 22:5(n-3), and DHA (Table 4).

DHA levels were higher in unfasted fish (3.2%) compared to an average of 7.4% for fish fasted between 20–80 d ($P < 0.05$).

Discussion

Results from this study indicated that body composition and fatty acid composition of channel catfish is influenced by fasting. During fasting, body composition was slightly affected. Water content in liver of starved fish increased after 20 d, then remained relatively constant. This is in agreement with other studies on channel catfish (Satoh et al. 1984) and brook trout *Salvelinus fontinalis* (Phillips et al. 1960). Increase in moisture levels in liver of fasted fish was accompanied by a concomitant decrease in lipid level. Percentage of lipid in liver decreased after the first 20 d of starvation, then remained relatively constant. This observation is in agreement with other studies with tilapia and plaice (Pandian and Raghuraman 1972; Johnston and Goldspink 1973). Johnston and Goldspink (1973) reported that after 84 d of starvation, percentage lipid of white muscle of plaice *Pleuronectes platessa* remained relatively constant after an initial decrease.

Results of the present study indicate that channel catfish are capable of surviving a period of fasting (up to 12 wk) with differential losses of protein and fat. In all three tissues analyzed (viscera, muscle, and liver), percentage moisture increased during fasting: 9.5% in viscera, 1.7% in muscle, and 9.2% in liver. This was accompanied by a concomitant decrease in percentage of fat in these tissues. During this study, percentage fat in the liver decreased 83%, in viscera decreasing 30%, and in muscle decreasing 38%. Percentage protein decreased 15% in viscera during 12 wk of fasting, but only 3% in muscle and was unchanged in liver.

During fasting, fish must utilize stored energy supplies for metabolic processes. Lipid (fat) depots in tissues offer an excellent source and appear to be the major source of energy over other nutrients, such as protein and carbohydrates, during fasting

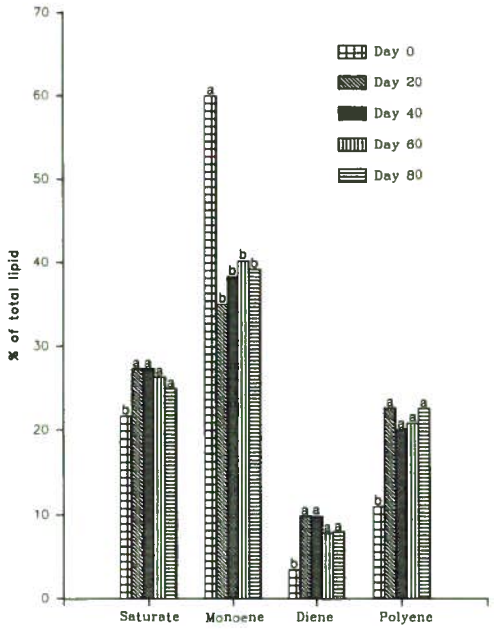

FIGURE 3. *Percentage of saturated, monoenoic, dienoic, and polyenoic fatty acids of liver from channel catfish starved for 0, 20, 40, 60, and 80 d. Bars within a lipid class with different letters were significantly different* ($P < 0.05$).

(Chang and Idler 1960). Takeuchi and Watanabe (1982) reported that percentage fat in viscera and muscle of carp *Cyprinus carpio* decreased rapidly after 30 d of fasting, but decreased very slowly during an additional 56 d of fasting. These authors also reported that the percentage fat in liver of rainbow trout decreased after 42 d of fasting.

In contrast to fat levels, protein appears to be spared during periods of fasting. Phillips et al. (1960) reported that whole-body protein levels in brook trout tended to increase or remain the same after 12 wk of fasting. These values fluctuated, however, between sampling periods. Satoh et al. (1984) reported that whole-body protein levels of fasted tilapia *Oreochromis niloticus* were similar after 60 d fasting compared to fish before fasting. In the present study, only the viscera had a decrease (12%) in protein level, while muscle and liver remained generally unchanged after 12 wk of fasting. This

TABLE 4. *Percentage of individual fatty acids (area %) in liver of channel catfish starved for 0, 20, 40, 60, and 80 d. Values are means ± SE of four replications. Means in the same row with different superscripts are significantly different (P < 0.05).*

Fatty acid	Days starved				
	0	20	40	60	80
16:0	13.14 ± 0.33^{c}	16.75 ± 0.28^{a}	16.78 ± 0.36^{a}	16.76 ± 0.34^{a}	14.53 ± 0.35^{b}
16:1(n-7)	2.07 ± 0.19^{a}	1.53 ± 0.16^{b}	1.31 ± 0.20^{b}	1.69 ± 0.13^{ab}	1.41 ± 0.08^{b}
18:0	7.91 ± 0.91^{a}	9.73 ± 0.54^{a}	9.84 ± 0.96^{a}	8.81 ± 0.33^{a}	9.71 ± 0.54^{a}
18:1(n-9)	56.01 ± 5.31^{a}	32.08 ± 1.39^{b}	35.44 ± 0.90^{b}	37.24 ± 0.86^{b}	35.67 ± 3.39^{b}
18:2(n-6)	2.79 ± 0.73^{b}	8.63 ± 0.72^{a}	8.51 ± 1.62^{a}	6.71 ± 0.34^{a}	6.68 ± 0.81^{a}
18:3(n-3)	0.32 ± 0.13^{c}	1.41 ± 0.20^{b}	1.41 ± 0.23^{b}	2.66 ± 0.39^{a}	0.99 ± 0.20^{bc}
20:1(n-9)	1.81 ± 0.12^{a}	1.31 ± 0.07^{b}	1.29 ± 0.12^{b}	1.15 ± 0.08^{b}	2.02 ± 0.22^{a}
20:2(n-6)	0.67 ± 0.14^{b}	1.31 ± 0.07^{a}	1.41 ± 0.12^{a}	1.21 ± 0.11^{a}	1.37 ± 0.20^{a}
20:3(n-6/n-9)	2.19 ± 0.57^{b}	2.31 ± 0.30^{b}	2.38 ± 0.16^{b}	1.90 ± 0.14^{b}	4.02 ± 0.10^{a}
20:4(n-6)	2.94 ± 0.80^{b}	4.48 ± 0.69^{ab}	3.88 ± 0.81^{ab}	4.40 ± 0.23^{ab}	5.73 ± 0.55^{a}
20:5(n-3)	0.23 ± 0.07^{c}	2.06 ± 0.21^{a}	1.40 ± 0.19^{b}	2.00 ± 0.25^{a}	0.83 ± 0.23^{b}
22:5(n-3)	2.24 ± 0.65^{b}	3.78 ± 0.27^{a}	3.65 ± 0.28^{a}	3.49 ± 0.22^{a}	4.05 ± 0.31^{a}
22:6(n-3)	3.19 ± 0.64^{b}	8.64 ± 0.67^{a}	7.49 ± 0.55^{a}	6.41 ± 0.52^{a}	7.01 ± 1.39^{a}
Other[1]	4.49	5.98	5.21	5.57	5.98

[1] Other fatty acids include: 8:0, 10:0, 11:0, 12:0, 13:0, 14:0, 14:1(n-5), 15:0, 15:1(n-5), 17:0, 17:1(n-7), 18:4(n-3), 20:3(n-3), 22:0, 22:1(n-9), 22:2(n-6), 22:4(n-6), 22:5(n-6), 24:0, 24:1(n-9), and unidentified fatty acids.

would imply that fasted channel catfish utilize fat as the preferred energy source, while protein, especially in muscle and liver, are conserved.

The tissue fatty acid composition of fasted fish is a reflection of the fatty acids required in these tissues (Koven et al. 1989). Fatty acid composition during starvation indicated that levels of DHA in liver and muscle were retained, implying a metabolic or structural need for DHA. Santha and Gatlin (1991) stated that channel catfish required n-3 HUFA to satisfy the essential fatty acid requirement. During starvation, n-3 HUFAs were conserved in gilthead seabream *Sparus aurata* with DHA being more strongly conserved than EPA (Koven et al. 1989). Starved dolphin fish *Coryphaena hippurus* also preferentially retain DHA (Ostrowski and Divakaran 1990). Murata and Higashi (1980) reported that DHA increased from 2.4% of the lipid in triacylglycerols of common carp to 56% after 66 d of fasting. The conservation of DHA in fish during fasting is in agreement with other studies (Martin et al. 1984; Satoh et al. 1984; Kiessling et al. 1989; Soivio et al. 1989; Tidwell et al. 1992).

It has been shown that certain tissues (e.g., retina) can selectively sequester DHA from the blood during n-3 fatty acid deficiency and recycle DHA within the tissue, although the mechanism is unknown (Stinson et al. 1991). It has been reported that DHA has a higher efficacy as an essential fatty acid than most fatty acids for several marine finfish species (Watanabe et al. 1989a, 1989b; Takeuchi et al. 1990). Periods of fasting during winter months are a part of the natural life cycle of many fish species and it has been reported that n-3 HUFA, especially DHA, are retained in the lipid of muscle and liver during fasting (Jezierska et al. 1982; Skuladottir et al. 1990).

A possible reason that fasted channel catfish in the present study retained DHA in muscle and liver tissues is to maintain physiologic and metabolic processes. Variability in the number of carbon atoms and the number of double bonds determine the physical properties of biological membranes (Stubbs and Smith 1984). Biomembranes contain large amounts of HUFA which confer fluidity to the membrane. Fluidity permits movement of protein (enzyme) molecules within the membrane,

which are essential for the function of the membrane and cells. Membranes with high percentages of HUFA have more fluidity than membranes that have high percentages of saturated fatty acids. Lee et al. (1967) stated that n-3 HUFA are selectively incorporated into phospholipids, which are of primary importance in biomembranes and are retained during fasting (Leger 1981). Thus, DNA and other essential HUFA are conserved because they are required for metabolic processes (Alfin-Slater and Aftergood 1968).

Interorgan transport of lipids in fasted fish is comprised of an endogenous transport system that delivers lipid to tissues and storage sites via the liver. When lipid stores are transported, free fatty acids (FFA) are released into the plasma and are stored in several depot organs including abdominal fat, muscle, and liver (Robinson and Mead 1973). The principal storage molecules of lipid are triacylglycerols. Mobilization of lipids is a result of lipolytic enzyme activity that results in the hydrolysis of stored triacylglycerols into constituent fatty acids (Sheridan 1988).

Results from the present study indicate that lipid levels in the liver and muscle of channel catfish decrease ($P < 0.05$) in fish which have been fasted for 20 d or longer. Data also indicate that the n-3 fatty acid, DHA, is conserved in fasted channel catfish tissues. Percentage of DHA increased in both liver and muscle during 20 d of fasting and remained at higher levels in tissues of fasted fish than in tissues of unfasted fish. However, DHA levels in muscle fluctuated during the study and were not different among fish fasted 80 d compared to unfasted fish. It appears that DHA is selectively conserved in liver (and to some extent in the muscle) to a greater degree than in abdominal fat, which has a low percentage of DHA.

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