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Restoration of fatty acid composition of common carp *Cyprinus carpio* (Linnaeus, 1758) fed terrestrial oil based diets using fish oil finishing diet

SONU BAWEJA AND BHUPINDER KAUR BABBAR
Department of Zoology, Punjab Agricultural University, Ludhiana - 141 004, Punjab, India
e-mail: sonubaweja3@gmail.com

ABSTRACT

This study investigated effects of fish oil finishing diets on growth performance, fatty acid profiles and proximate composition of common carp *Cyprinus carpio.* Three isonitrogenous, isolipidic and isoenergetic diets were formulated. Diet 1 contained 50% fish oil and 50% canola oil and Diet 2 contained 50% fish oil and 50% poultry fat. The finishing diet (Diet 3) contained 100% fish oil. Fish were given different dietary treatments *viz.,* T1 = 60 day feeding with Diet 1, T2 = 40 day (1-40) feeding with Diet 1 and 20 day (41-60) feeding with Diet 3, T3 = 60 day feeding with Diet 2, T4 = 40 day (1-40) feeding with Diet 2 and 20 day (41-60) feeding with Diet 3 and T5 = 60 day feeding with Diet 3. There was non-significant difference in the growth performance and proximate composition of fish in all the treatments. Inducing a dietary shift from canola oil based and poultry fat based feeds to fish oil based feeds supplied as finishing diet (*i.e.,* T2 and T4) significantly increased long-chain PUFA concentrations in common carp as compared to those fed only canola oil (T1) and poultry fat (T3) based feeds. Amongst T2 and T4, treatment T2 appeared to be better with comparatively higher n-3 PUFAs and n-3/n-6 ratio.

Keywords: Canola oil, Common carp, Fatty acids, Finishing diet, Poultry fat

Introduction

The need for fish oil for aquafeed production is viewed as the most demanding obstacle to overcome sustainable development of the aquaculture sector (Naylor *et al*., 2009). Consequently, the substitution of fish oil in aquafeed formulations with readily available and more economical terrestrial alternatives has been the object of intensive research effort (Turchini *et al*., 2009). This research focus has widely demonstrated that the substitution of fish oil with any alternative source results in a reflection of the dietary fatty acid composition in fish flesh, a potentially undesirable trait from an omega-3 long chain polyunsaturated fatty acid (n-3 LC-PUFA) consumption viewpoint (Rosenlund *et al*., 2010). Terrestrial alternatives to fish oil are characterised by a wide range of fatty acid compositions and are notably lacking in meaningful concentrations of LC-PUFA (Turchini *et al*., 2010). One way to boost the LC-PUFA concentration of farmed fish fed on alternative lipid sources may be to use 'finishing' feeds containing 100% fish oil. The fatty acid composition of the fish flesh could thus be altered to meet the consumer expectation of a product that is rich in n-3 highly unsaturated fatty acids (n-3 HUFAs) and low in n-6 fatty acids (Jobling *et al*., 2002; Bell *et al*., 2003a, b; Glencross *et al*., 2003; Robin *et al*., 2003). Consumption of food rich in n-3 HUFA particularly fish, which are a good source of eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3) are beneficial for human health (Mozaffarian and Rimm, 2006). These fatty acids (FA) play an important role in biological functions, including brain development, inflammatory response, homeostasis and prevention of cardiovascular disease (Calder, 2006; Calder and Yaqoob, 2010).

Such a finishing diet strategy has been suggested and developed for carnivorous fish species, including medium fatty fish species such as turbot (*Psetta maxima*) (Robin *et al*., 2003), fatty fish such as Atlantic salmon (*Salmo salar*) (Jobling, 2003; 2004) and lean fish species such as Atlantic cod (*Gadus morhua*) (Jobling *et al*., 2008) and Murray cod (*Maccullochella peelii peelii*) (Turchini *et al*., 2006). The results so far have been promising and adoption of finishing feed strategy for commercial applications has been proposed.

Common carp (*Cyprinus carpio*) is one of the most widely cultured fish species globally (FAO, 2008) with a production volume of around 0.3 million t annually (FAO, 2010). Thus, from a worldwide nutrition perspective, a method to increase the amount of n-3 HUFA in carp fillet is valuable. Optimisation of the fatty acid composition of carp has been examined in previous studies (Steffens, 1997; Domaizon *et al*., 2000; Steffens and Wirth, 2007; Chen *et al*., 2011; Mraz *et al*., 2012). Mraz and Pickova

(2011) concluded that adjusting the lipid composition in the feed is the most effective tool to achieve the desired n-3 HUFA content. Therefore the aim of this study was to examine the applicability of finishing diet in common carp production with defined and tailored flesh quality for specific needs in human nutrition.

Materials and methods

Experimental diets

Three isonitrogenous, isolipidic and isoenergetic diets were formulated. The diets had identical ingredient compositions, except from the lipid source (Table 1). No fish meal was used, in order to avoid high background levels of n-3 HUFA in the diet. Diet 1 contained 50% fish oil and 50% canola oil and Diet 2 contained 50% fish oil and 50% poultry fat. The finishing diet (Diet 3) contained 100% fish oil. Formulation and proximate composition of experimental diets is given in Table 1 and the fatty acid composition of the experimental diets is listed in Table 2. After proper washing of poultry fat inorder to remove any clotted blood and sorting out of any attached tissues to the fat, it was heated in a pan on a hot plate at 120°C till the water evaporated and the oil became clear which was then filtered in a strainer. Clear and sparkling oil extracted from poultry fat was then used for incorporation during the preparation of feeds.

Table 1. Formulation and proximate composition of experimental diets

Ingredients (%)	Diets		
	Diet 1	Diet 2	Diet 3
Fish oil	10	10	20
Canola oil	10	-	-
Poultry fat	-	10	-
Soybean meal	20	20	20
Groundnut oil cake	20	20	20
Mustard oil cake	20	20	20
Wheat flour	5	5	5
Rice bran	5	5	5
Corn starch	5	5	5
Vitamin & mineral mixture	1	1	1
Molasses	3.5	3.5	3.5
Iodised salt	0.5	0.5	0.5
Proximate composition (%)			
Moisture	5.11±0.08	5.15±0.11	5.21±0.08
Crude protein	25.95±0.77	26.24±0.50	26.83±0.58
Total lipid	20.06±0.13	20.10±0.15	19.93±0.13
Ash	8.43±0.07	8.36±0.04	8.43±0.07
Carbohydrate	40.42±0.75	40.07±0.26	39.58±0.80

Diet 1: 50% fish oil+50% canola oil; Diet 2: 50% fish oil+50% poultry fat; Diet 3: 100% fish oil

Table 2. Fatty acid composition of experimental diets

Fatty acid (%)	Diets		
	Diet 1	Diet 2	Diet 3
10:0	2.54±0.42^{b}	2.32±0.06^{c}	3.89±0.31^{a}
11:0	0.86±0.14^{b}	0.76±0.00^{c}	1.66±0.04^{a}
14:0	3.56±0.32^{b}	1.79±0.10^{c}	3.92±0.38^{a}
16:0	11.48±0.62^{c}	23.24±1.24^{a}	17.5±0.64^{b}
18:0	7.21±0.58^{c}	8.39±0.08^{b}	12.31±0.40^{a}
ΣSFA	25.65±0.98^{c}	36.50±0.36^{b}	39.28±0.94^{a}
18:1 n-9	42.26±0.45^{a}	34.82±0.25^{b}	25.84±0.28^{c}
Σ MUFA	42.26±0.45^{a}	34.82±0.25^{b}	25.84±0.28^{c}
18:3 n-3	11.13±0.35^{b}	6.90±0.05^{c}	12.40±0.73^{a}
20:5 n-3	1.24±0.02^{b}	1.18±0.02^{c}	2.46±0.30^{a}
22:6 n-3	1.51±0.12^{b}	1.45±0.01^{b}	3.04±0.08^{a}
Σn-3PUFA	13.88±0.38^{b}	9.53±0.13^{c}	17.90±0.35^{a}
18:2 n-6	14.20±0.65^{b}	14.98±0.12^{a}	9.51±0.09^{c}
20:4 n-6	3.22±0.09^{c}	3.57±0.02^{b}	5.75±0.21^{a}
Σn-6PUFA	17.42±0.62^{b}	18.55±0.11^{a}	15.26±0.25^{c}
ΣPUFA	31.30±0.98^{b}	28.08±0.58^{c}	33.16±1.45^{a}
Σ UFA	73.56±0.54^{a}	62.90±1.71^{b}	59.00±1.20^{c}
n3/n6	0.80±0.04^{b}	0.51±0.00^{c}	1.17±0.05^{a}
SFA/PUFA	0.82±0.02^{c}	1.30±0.03^{a}	1.18±0.03^{b}
SFA/UFA	0.35±0.03^{c}	0.58±0.02^{b}	0.66±0.04^{a}
18:1 n-9/n-3	3.04±0.12^{b}	3.65±0.03^{a}	1.44±0.02^{c}

Diet 1: 50% fish oil+50% canola oil; Diet 2: 50% fish oil+50% poultry fat; Diet 3: 100% fish oil; ΣSFA includes Capric acid (10:0), Undecyclic acid (11:0), Myristic acid (14:0), Palmitic acid (16:0) and Stearic acid (18:0); ΣMUFA includes Oleic acid (18:1n-9); Σn-3 PUFA includes Linolenic acid (18:3n-3), Eicosapentaenoic acid (20:5n-3) and Docosahexaenoic acid (22:6n-3); Σn-6 PUFA includes Linoleic acid (18:2n-6) and Arachidonic acid (20:4n-6); ΣPUFA includes Σn-3 PUFA and Σn-6 PUFA; ΣUFA includes ΣPUFA and ΣMUFA; Values are means±S.E; Values with different superscripts in a row differ significantly ($p \leq 0.05$)

Experimental design and sampling

Common carp, *C. carpio* fingerlings were procured from the Sahib Bachan Farm, Pandori, Ludhiana, Punjab, India and acclimatised for one week to laboratory conditions in 100 l plastic tubs. The experiment was run in triplicates for 60 days in 15 plastic tubs of 34 l capacity each, holding 25 l water, fitted with complete aeration and filtration systems. Twelve fishes were stocked in each tub. The level of 25 l of water in each tub was maintained throughout the experiment by adding fresh dechlorinated water inorder to compensate the daily loss of water through evaporation. Entire water in each tub was changed after every month throughout the 60 day feeding experiment. Fish were given different dietary treatments *viz.,* T1 = 60 day feeding with Diet 1, T2 = 40 day (1-40) feeding with Diet 1 and 20 day (41-60) feeding with Diet 3, T3 = 60 day feeding with Diet 2, T4 = 40 day (1-40) feeding with Diet 2 and 20 day (41-60) feeding with Diet 3 and T5 = 60 day feeding with Diet 3. Fish were fed twice daily on experimental diets @5% of fish biomass.

At the end of the experiment, each fish was descaled, finned, beheaded and gutted. The fish samples were then cleaned with tap water and the muscle tissues were collected from whole fish body. Bones were removed and the boneless muscles were thoroughly mixed to form a composite or representative sample of edible portion of the fish. The whole procedure was done on ice that took about 10 min. The tissue samples were packed in clean labelled ziploc polythene bags and stored at -25^{0}C for further analyses.

Water quality parameters

The weekly water quality parameters *viz.,* total alkalinity, total hardness, salinity, dissolved oxygen (DO) and ammonia were estimated by the standard methods (APHA, 1991). Water temperature was recorded with the help of an ordinary mercury thermometer (0-50°C) and pH was recorded using a digital pH meter (model ELICO LI120).

Survival and growth performance

Survival (%) was calculated by comparing the live fishes recovered at the end of the experiment with the total number stocked at the start of the experiment. Growth was estimated in terms of net weight gain (NWG), average daily weight gain (ADWG) and specific growth rate (SGR) using the following formulae:

$$NWG\ (g) = \text{Final body weight (g)} - \text{Initial body weight (g)}$$

$$ADWG\ (\%W\ d^{-1}) = \frac{\text{Average final body weight - Average initial body weight}}{\text{Period of culture (days)}}$$

$$SGR\ (\%W\ d^{-1}) = \frac{L_n \text{ final body weight} - L_n \text{ initial body weight}}{\text{Period of culture (days)}} \times 100$$

Biochemical composition analysis

Proximate analysis of experimental diets and fish flesh was done following standard procedures (AOAC, 2000). Percentage moisture was determined by drying 2 g sample at 100±2°C (to constant weight), crude proteins (CP) measured by Kjeldhal method, total lipid content by solvent extraction method and ash by incineration in a muffle furnace. Carbohydrate content was calculated by difference (FAO, 2004): % Carbohydrate = 100 – (% moisture + % crude proteins + % total lipids + % ash)

Fatty acid analysis was carried out by Gas Chromatography (AOAC, 2000) using M/s Nucon Engineers AIMIL Gas Chromatograph (solid state) model Nucon series 5700/5765 equipped with flame ionisation detector.

Statistical analysis

The data on survival, growth performance, proximate and fatty acid composition were subjected to one-way analysis of variance (ANOVA) with the help of STATGRAPH and Microsoft Excel. Differences were regarded as significant at $p \leq 0.05$.

Results

Water quality parameters

Water quality parameters showed no statistically significant differences between different dietary treatment systems, and the observed values indicated that none of the experimental diets affected the quality of water. Water quality parameters were within the suitable range for grow out of the species (Table 3).

Table 3. Water quality parameters recorded during the experimental period

Treatment*		Temperature (°C)	DO (mg l^{-1})	pH	Alkalinity (mg l^{-1})	Hardness (mg l^{-1})	Ammonia (mg l^{-1})	Salinity (ppt)
T1	Mean	31.11	9.22	7.48	111.86	228.20	0.33	0.051
	Max.	36.50	9.45	7.64	117.33	239.33	0.37	0.060
	Min.	25.00	8.80	7.30	105.33	218.66	0.29	0.040
T2	Mean	31.11	9.32	7.54	111.33	228.46	0.34	0.053
	Max.	36.50	9.60	7.72	116.67	237.33	0.35	0.060
	Min.	25.00	8.93	7.17	104.67	220.00	0.31	0.048
T3	Mean	31.11	9.34	7.57	112.26	230.13	0.34	0.053
	Max.	36.50	9.60	7.71	118.00	238.66	0.35	0.061
	Min.	25.00	9.06	7.40	105.33	221.33	0.31	0.043
T4	Mean	31.11	9.22	7.51	112.06	235.00	0.34	0.049
	Max.	36.50	9.60	7.67	118.00	244.00	0.36	0.056
	Min.	25.00	8.80	7.27	103.33	225.33	0.32	0.040
T5	Mean	31.11	8.97	7.53	112.00	231.06	0.33	0.054
	Max.	36.50	9.33	7.66	116.67	240.00	0.35	0.060
	Min.	25.00	8.26	7.36	106.00	221.33	0.29	0.050

T1=60 day feeding with Diet 1; T2=40 day (1-40) feeding with Diet 1 and 20 day (41-60) feeding with Diet 3; T3=60 day feeding with Diet 2; T4=40 day (1-40) feeding with Diet 2 and 20 day (41-60) feeding with Diet 3, T5= 60 day feeding with Diet 3; Values are mean±S.E

Growth

Average daily weight gain (ADWG) of fish were not significantly different (0.013-0.014 g) among different dietary treatments. The NWG and SGR of fish ranging from 0.82-0.85 g and 0.23-0.24%, respectively were not significantly different among different treatments (Table 4). At the end of the experiment, survival was 100% in all the treatments (Table 4).

Proximate composition

The data on proximate composition of common carp fed different experimental diets are given in Table 5. No significant differences were detected in moisture, crude protein, total lipid, ash and carbohydrate content among different treatments.

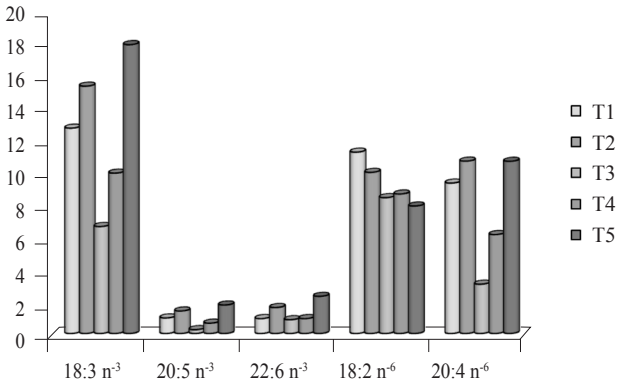

Fig. 1. Levels of selected essential fatty acids of *C. carpio* fed different experimental diets

Table 4. Growth performance of *Cyprinus carpio* fed different experimental diets

Parameters	Treatments				
	T1	T2	T3	T4	T5
ADWG (%W day^{-1})	0.013±0.001	0.014±0.001	0.013±0.001	0.014±0.001	0.014±0.001
NWG (g)	0.83±0.02	0.85±0.01	0.82±0.01	0.84±0.01	0.85±0.00
SGR (%W day^{-1})	0.23±0.00	0.24±0.00	0.23±0.01	0.23±0.00	0.24±0.00
Survival (%)	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00

Values are means±S.E

Table 5. Proximate composition (%) of *Cyprinus carpio* fed different experimental diets

Parameters	Treatments				
	T1	T2	T3	T4	T5
Moisture	75.45±0.52	74.11±0.31	74.40±0.75	73.96±0.28	74.20±0.76
Crude protein	14.58±0.50	14.58±0.50	14.58±0.29	14.28±0.58	14.87±0.50
Total lipid	3.78±0.02	3.92±0.08	3.94±0.07	3.95±0.07	3.87±0.07
Ash	1.43±0.04	1.40±0.07	1.48±0.06	1.46±0.04	1.43±0.04
Carbohydrate	5.53±0.40	5.99±0.64	5.59±0.82	6.35±0.92	5.63±0.40

Values are means±S.E

Fatty acid composition

Muscle fatty acid composition of total lipids showed the effect of the dietary treatment. There was significant difference ($p \leq 0.05$) in the concentration of SFAs, MUFAs and PUFAs in the muscle of *C. carpio* fed different experimental diets (Table 6). Total SFA was observed in higher concentrations in T5 (32.30±0.05%) followed by T4 (30.14±0.15%), T3 (28.78±0.22%), T2 (26.50±0.31%) and T1 (23.44±0.60%). Palmitic acid (16:0) was the predominant SFA in all the treatments except in T5 where stearic acid (18:0) was the predominant SFA. Level of the only MUFA, oleic acid (18:1) was maximum in T1 (37.01±1.38%) and minimum in T5 (9.40±0.32%). The highest total n-6 fatty acids were found in T1 (21.00±0.47%) and T2 (21.10±0.27%) followed by T5 (18.98±0.13%), T4 (15.09±0.10%) and T3 (11.72±0.0). On the other hand, total n-3 fatty acids were highest in T5 (22.11±0.22%) followed by T2 (19.73±0.16%), T1 (14.95±0.53%), T4 (11.74±0.08%) and T3 (7.83±0.05%). Fig. 1 shows the levels of certain essential fatty acids in the fish muscle fed different experimental diets. The n-3/n-6 ratio was maximum (1.16±0.01) in T5 and lowest in T1 (0.67±0.04) and T3 (0.66±0.00). Differences in n-3/n-6 ratio were statistically significant ($p \leq 0.05$) (Table 6, Fig. 2). The SFA/PUFA, SFA/UFA and 18:1 n-9/n-3 ratios were highest in T3 and T4 respectively (Fig. 3).

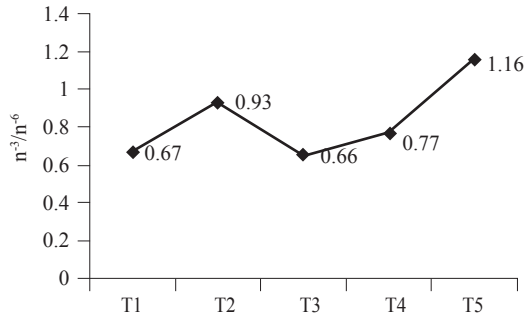

Fig. 2. n-3/n-6 ratio of *C. carpio* fed different experimental diets

Table 6. Fatty acid composition of *Cyprinus carpio* fed different experimental diets

Fatty acid (%)	Treatments				
	T1	T2	T3	T4	T5
10:0	2.75±0.38^{c}	3.32±0.03^{b}	2.33±0.26^{d}	3.26±0.03^{b}	4.25±0.04^{a}
11:0	1.42±0.31^{c}	2.04±0.03^{b}	0.73±0.12^{d}	1.40±0.06^{c}	2.26±0.07^{a}
14:0	0.39±0.04^{d}	0.26±0.02^{a}	0.20±0.01^{c}	0.25±0.01^{a}	0.20±0.01^{b}
16:0	14.86±0.17^{bc}	11.88±0.12^{b}	19.80±0.01^{b}	15.10±0.05^{a}	9.58±0.15^{c}
18:0	4.01±0.16^{g}	8.98±0.17^{c}	5.062±0.00^{f}	9.98±0.21^{b}	16.01±0.12^{a}
ΣSFA	23.44±0.60^{f}	26.50±0.31^{c}	28.78±0.22^{e}	30.14±0.15^{b}	32.30±0.05^{a}
18:1 n-9	37.01±1.38^{c}	27.68±1.23^{a}	36.05±0.01^{b}	27.78±0.30^{a}	9.40±0.32^{b}
Σ MUFA	37.01±1.38^{c}	27.68±1.23^{a}	36.05±0.01^{b}	27.78±0.30^{a}	9.40±0.32^{b}
18:3 n-3	13.00±0.60^{c}	15.66±0.14^{b}	6.77±0.00^{d}	10.15±0.09^{c}	18.29±0.07^{a}
20:5 n-3	0.98±0.09^{b}	1.42±0.06^{b}	0.24±0.02^{d}	0.65±0.03^{c}	1.80±0.03^{a}
22:6 n-3	0.95±0.02^{c}	1.64±0.04^{b}	0.87±0.03^{c}	0.94±0.03^{c}	2.35±0.02^{a}
Σn-3PUFA	14.95±0.53^{c}	19.73±0.16^{b}	7.83±0.05^{d}	11.74±0.08^{c}	22.11±0.22^{a}
18:2 n-6	11.48±0.96^{a}	10.20±0.14^{a}	8.60±0.00^{a}	8.83±0.06^{b}	8.07±0.11^{c}
20:4 n-6	9.52±0.50^{e}	10.91±0.24^{a}	3.12±0.00^{c}	6.26±0.06^{b}	10.90±0.07^{a}
Σn-6PUFA	21.00±1.46^{c}	21.10±0.27^{a}	11.72±0.0^{b}	15.09±0.10^{c}	18.98±0.13^{b}
ΣPUFA	35.95±1.65^{b}	40.83±0.36^{b}	19.61±0.06^{c}	26.84±0.17^{c}	41.09±0.24^{a}
Σ UFA	72.96±1.70^{a}	68.35±1.09^{a}	55.66±0.08^{a}	54.62±0.40^{b}	50.48±0.47^{c}
n3/n6	0.67±0.04	0.93±0.01^{b}	0.66±0.00^{e}	0.77±0.00^{c}	1.16±0.01^{a}
SFA/PUFA	0.65±0.04^{e}	0.65±0.01^{c}	1.47±0.01^{e}	1.12±0.01^{a}	0.78±0.00^{b}
SFA/UFA	0.32±0.01^{e}	0.38±0.00^{c}	0.51±0.00^{e}	0.55±0.00^{b}	0.63±0.01^{a}
18:1 n-9/n-3	2.47±0.02^{d}	1.40±0.06^{b}	4.60±0.03^{c}	2.36±0.03^{a}	0.42±0.01^{c}

ΣSFA includes Capric acid (10:0), Undecyclic acid (11:0), Myristic acid (14:0), Palmitic acid (16:0) and Stearic acid (18:0); ΣMUFA includes Oleic acid (18:1n-9); Σn-3 PUFA includes Linolenic acid (18:3n-3), Eicosapentaenoic acid (20:5n-3) and Docosahexaenoic acid (22:6n-3); ^{d}Σn-6 PUFA includes Linoleic acid (18:2n-6) and Arachidonic acid (20:4n-6); ΣPUFA includes Σn-3 PUFA and Σn-6 PUFA; ΣUFA includes ΣPUFA and ΣMUFA; Values are means ± S.E; Values with different superscripts in a row differ significantly ($p \leq 0.05$)

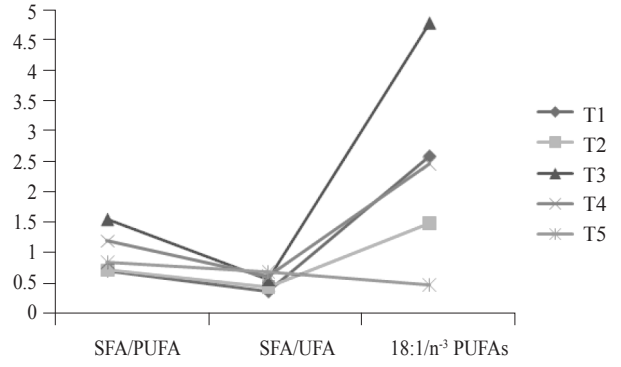

Fig. 3. SFA/PUFA, SFA/UFA and 18:1 n-9/n-3 ratios of *C. carpio* fed different experimental diets

Discussion

In this study, it was shown that, irrespective of any significant difference in the growth performance and proximate composition of common carp received different dietary treatments, a 20 days feeding of fish oil based finishing feed improved the fatty acid composition. The 20 days supplementation of finishing feed at the end of the cultivation period markedly increased n-3 PUFA concentrations of common carp. The diet shift from canola oil and poultry fat, poor in n-3 PUFA to finishing feed rich in n-3 PUFA indicated that common carp very efficiently retained high quality supplementary feeds within a short period of time. This is in agreement with previous findings that it is possible to boost the content of beneficial EPA and DHA in fish fillet by n-3 HUFA supplementation prior to harvest in Atlantic salmon (Bell *et al*., 2004; Torstensen *et al*., 2005); in gilthead sea bream (Benedito-Palos *et al*., 2009); in common carp (Steffens, 1997; Steffens and Wirth, 2007); and in murray cod (Turchini *et al*., 2006).

PUFA conversions are known to occur in a variety of freshwater fish species (Buzzi *et al*., 1996, 1997; Tocher *et al*., 2006), including common carp (Farkas *et al*., 1980; Tocher and Dick, 1999). It was also demonstrated that dietary LA and ALA stimulate gene expression of desaturases and elongases (Zheng *et al*., 2005). However, for many freshwater fish species, the conversion of C18 PUFA to long-chain PUFA seems to occur at a very slow rate (Tocher *et al*., 2006) because of limiting delta-6 and delta-5 desaturation steps (Buzzi *et al*., 1996, 1997; Tocher *et al*., 2006; Vagner and Santigosa, 2011). In this study, feeding C18 PUFA rich feed to common carp did not result in considerable conversion to long-chain PUFA-enriched fish. Although previous studies in common carp suggest that, compared with C18-PUFA, dietary C20-22 PUFA requirements for carp are low (Radunz-Neto *et al*.,

1996; Glencross, 2009). Present study showed an increase in C20–22 PUFA in carp exposed to finishing feed for only 20 days. Schultz *et al.* (2014) reported that supply of short chain PUFA to carp resulted in higher short chain but not long chain PUFA indicating little PUFA conversion in carp. However moderate supply of dietary long chain PUFA in finishing diet increased long chain PUFA concentration in carp.

It is evident from the present study that short-term supplementation of fish oil results in significantly higher C20-22 PUFA concentrations compared with those fed 50% canola oil feed and 50% poultry fat feed throughout the experimental period. Absorption efficiency of dietary fatty acids in fish is known to increase with the degree of fatty acid unsaturation, chain length and position of the first double bond (n-3>n-6>n-9 fatty acids; Olsen *et al*., 1998; Francis *et al*., 2007). Therefore, it can be suggested that the lower accumulation of C20-22 n-3 PUFA in the treatment T1 and T3 is primarily the result of limited dietary C20-22 n-3 PUFA supply along with low endogenous bioconversion rates of C18 PUFA, whereas higher dietary supply and potentially highly efficient uptake of dietary EPA and DHA supplied by fish oil feeds accounts for the rapid increase in EPA and DHA within the 20 days of feeding the finishing diet. Finally, these results suggest that such increase in highly desirable PUFA may potentially lead to increased fish performance (Bell *et al*., 1998), subsequently to higher fish quality with respect to enhanced fish production yields (Copeman *et al*., 2002), and to increased nutritional values for human consumption. Percent reduction in the cost of lipids in T1, T2, T3 and T4 is 43%, 28.63%, 49.27% and 32.81% respectively. Comparison of different dietary treatments (T1, T2, T3 and T4) on the basis of both fatty acid compositions and cost of lipids in treatments revealed that T2 is the best treatment as it reduced the cost of lipids in feed by 28.63% and also increased n-3 PUFAs in fish feed.

Beneficial from fish fitness and human nutrition perspectives, C20-22 PUFA were increased in carp fed finishing feed for 20 days of the experimental period compared with those exposed only to canola oil and poultry fat based feeds for the whole experimental period. Canola oil and poultry fat based feeds can be used as suitable alternatives to reduce use of marine resources in aquaculture nutrition if fish oil based finishing diet is fed to fish for a short period before harvest to increase n-3 PUFA concentrations in common carp. This feeding strategy could therefore be used in production of common carp with defined flesh quality to fulfill dietary needs for humans. By adopting this strategy, fish farmers could easily control the final carp flesh quality and produce fish with standardised and tailored quality which could increase the market value of common carp and support consumption of this locally produced fish.

In conclusion, the results of the present study suggests that inducing a dietary shift from terrestrial oil (vegetable oil or animal fat) based feeds to fish oil based feeds supplied as finishing diet before harvesting strongly increases long chain PUFA concentration in common carp as compared to those fed only terrestrial oil based feeds throughout the rearing period.

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