The replacement of fish oil with refined coconut oil in the diet of large rainbow trout (Oncorhynchus mykiss)

Rodolfo Ballestrazzi, Simona Rainis & Marco Maxia

To cite this article: Rodolfo Ballestrazzi, Simona Rainis & Marco Maxia (2006) The replacement of fish oil with refined coconut oil in the diet of large rainbow trout (Oncorhynchus mykiss), Italian Journal of Animal Science, 5:2, 155-164, DOI: 10.4081/ijas.2006.155

To link to this article: http://dx.doi.org/10.4081/ijas.2006.155
The replacement of fish oil with refined coconut oil in the diet of large rainbow trout (Oncorhynchus mykiss)

Rodolfo Ballestrazzi¹, Simona Rainis², Marco Maxia¹

¹Dipartimento di Scienze Animali. Università di Udine, Italy
²Associazione Allevatori Friuli Venezia Giulia. Codroipo (UD), Italy

Corresponding author: Prof. Rodolfo Ballestrazzi. Dipartimento di Scienze Animali. Università di Udine. Via S.Mauro 2, 33010 Pagnacco (UD), Italy – Tel. +39 432 650110 – Fax: +39 432 660614 – Email: rodolfo.ballestrazzi@uniud.it

Paper received October 13, 2005; accepted January 6, 2006

ABSTRACT

Three hundred rainbow trout (242.9 ± 6.9 g) were randomly assigned to 12 fibreglass tanks (25 fish/tank). The fish were fed, for 231 days (feeding level: 0.74 % average bw), four experimental diets, containing increasing levels of coconut oil: diet A 0 %, diet B 6 %; diet C 12 % and diet D 13 %, as replacements of herring oil and cod liver oil. Weight gains of fish were > 3 g d⁻¹ and FCR lower than 1.5, for all treatments. No significant difference was observed in the main carcass traits and whole body composition, but whole fish energy content significantly increased in fish fed diet D (10.68 KJ g⁻¹). Different dietary fatty acid profiles had significant effects on the rainbow trout muscle contents of C10:0, C12:0, C14:0, total n-3, and the main ratios: SFA/USFA; DHA/EPA; DHA/AA, n-3/n-6, but not on total fatty acids content of the muscle.

Key words: Rainbow trout, Oncorhynchus mykiss, Refined coconut oil, Performance, Muscle fatty acid composition.

RIASSUNTO

LA SOSTITUZIONE DELL’OLIO DI PESCE CON OLIO DI COCCO RAFFINATO NELLA DIETA DI TROTA IR IDEA (ONCHORHYNCHUS MYKISS) DI GRANDE PORZIONE

Trecento trote iridea (242,9 ± 6,9 g) sono state distribuite casualmente in 12 vasche di vetroresina (25 pesci/vasca). I pesci sono stati alimentati, per 231 giorni (livello alimentare: 0,74 % peso vivo medio), con quattro diete sperimentali, contenenti livelli crescenti di olio di cocco: dieta A 0 %, dieta B 6 %; dieta C 12 % e dieta D 13 %, in sostituzione dell’olio di aringa e dell’olio di fegato di merluzzo. Gli accrescimenti ponderali sono risultati > 3 g d⁻¹ e gli indici di conversione alimentare minori di 1,5, per tutti i trattamenti. Non si sono osservate differenze significative per i principali parametri di macellazione e la composizione corporea ma il contenuto energetico del pesce intero è significativamente aumentato nei pesci alimentati con la dieta contenente solamente olio di cocco (D: 10,68 KJ g⁻¹). I differenti profili acidici della dieta hanno avuto effetti significativi sui contenuti di C10:0, C12:0, C14:0, n-3 totali del muscolo della trota iridea, nonché i principali rapporti: AG Saturi/AG Insaturi, DHA/EPA; DHA/AA, n-3/n-6, ma non sul contenuto di acidi grassi totali del muscolo.

Parole chiave: Trota iridea, Oncorhynchus mykiss, Olio di cocco raffinato, Prestazioni produttive, Composizione acidica del muscolo.
Introduction

World fish oil production recently exceeded 1.36 x 10^6 t (FAO, 2002). Some authors reported that more than 70% is the most reliable estimate of its use by the aquaculture feed industry (Olsen et al., 2004). Unfortunately, fish oil is a generic word which includes very different types, according to species, period of the year, latitude of catch, and chemical features (Bimbo, 1990), and it is characterised by fluctuating prices, depending on the variability of the catch by the fishery industry. Nevertheless, fish oils are widely abused in fish feeds, at least in salmonid and marine species feeding. In fact, in recent decades aquaculture diets have seen a progressive increase in fat levels: from 10-12% (in the formulations of the 70s) up to 35% and more, for Atlantic salmon feeds (Eiinan and Roem, 1997). This increase has been obtained using almost exclusively fish oils, although in the past many experiments demonstrated the possibility of fish oil replacement with alternative plant or vegetable oils or animal fats (Stickney and Andrews, 1972; Mugritchian et al., 1981; Reinitz and Yu, 1981; Yu and Sinnhuber, 1981). No adverse effects of these alternative ingredients had been generally detected, up to certain substitution rates in the diets, although some vegetable oils have particular fatty acids composition. Sargent et al. (2002) observed that the fish performance and body composition are not influenced by dietary fat levels up to 20%, but the same authors noted that feeding high levels of unsaturated lipids (i.e. fish oils) could raise the peroxidant stress on fish consuming these ingredients. Furthermore, the general situation of these ingredients on the international market should encourage reconsideration of the spectrum of lipid sources useful for fish feed. The choice of the lipid ingredients by feed companies is made with stringent quality controls (peroxide value, iodine number, anomalous fatty acids contents), and also taking into consideration the constant availability of the source rather than a priori refusal for their origin or their saturated fatty acid content. Consequently, the lipids of plant origin need to be evaluated, also in coldwater species, in the general framework of seeking to spare fish oils (FAO, 2002).

This research was performed in order to evaluate the effects of isolipidic diets, characterized by an increasing replacement of fish oils with coconut oil, on performance, body composition and muscle fatty acid composition of large rainbow trout (Oncorhynchus mykiss).

Material and methods

Diets

Four isoproteic (GP= 49.4 %DM) and isolipidic (EE= 18 %DM) experimental diets were prepared with ingredients commonly used for fish nutrition (Table 1). In diet A the lipid sources were: 12% herring oil and 1% cod liver oil; in diets B and C, herring oil was replaced by coconut oil at a rate of 50% and 100%, respectively, and in diet D coconut oil (13% inclusion rate) was also used as a substitute for cod liver oil (Table 1). Diets were processed through a pellet mill (Tenchini, mod. FT180). The proximate composition of the diets was determined according to A.O.A.C. methods (1995), as reported in Table 1.

Fish and facilities

Three hundred rainbow trout (RB) (Oncorhynchus mykiss) were randomly distributed in 12 fibreglass tanks (600 L), each supplied with a constant flow of well water (0.5-0.7 l·sec^-1). Triplicate groups of fish per diet were fed, using automatic belt feeders, 4 times a day (at 8.30 - 11.30 - 14.30 – 17.30), 6 days a week. Mortality, dissolved oxygen (7.2 ± 0.4 mg L^-1) and temperature of the water (12.5 ± 0.1°C) were checked daily, while the fish were weighed in a bulk, every 21 days, and feeding rates were adjusted accordingly. The trial lasted 231 days.

Analyses

Ten fish were sacrificed at the beginning of the trial and five fish per tank at the end, to determine carcass traits and body composition. For whole body composition, the gastrointestinal contents were removed and then each fish was minced and freeze-dried. Moisture, crude protein, ether extract and ash contents were analysed according to AOAC methods (1995). The energy content of diets and fish were determined by adiabatic calorimetry (IKA C400). From three-four fish per tank a muscle sample (5x2x3 cm, without skin) was taken.
REFINED COCONUT OIL IN RAINBOW TROUT DIET

Table 1. Formulation (g/kg⁻¹ diet), proximate composition (% DM) and energy content (kJ/kg⁻¹ diet) of the experimental diets.

| Diets | A         | B         | C         | D         |
|-------|-----------|-----------|-----------|-----------|
| Formulation: |           |           |           |           |
| Herring meal (999) | 230 | 230 | 230 | 230 |
| Soybean meal | 250 | 250 | 250 | 250 |
| Soybean prot. concentrate | 85 | 85 | 85 | 85 |
| Corn gluten meal | 120 | 120 | 120 | 120 |
| Brewery yeast | 50 | 50 | 50 | 50 |
| Herring oil | 120 | 60 | 0 | 0 |
| Cod liver oil | 10 | 10 | 10 | 0 |
| Coconut oil | 0 | 60 | 120 | 130 |
| Wheat starch pregelat. | 109.5 | 109.5 | 109.5 | 109.5 |
| Vitamin premix¹ | 5 | 5 | 5 | 5 |
| Mineral premix² | 5 | 5 | 5 | 5 |
| Choline | 2.5 | 2.5 | 2.5 | 2.5 |
| Lysine | 3 | 3 | 3 | 3 |
| Binder | 10 | 10 | 10 | 10 |

Proximate composition:

|                  | A         | B         | C         | D         |
|------------------|-----------|-----------|-----------|-----------|
| Dry matter %     | 92.3 ± 0.2| 92.3 ± 0.1| 91.7 ± 0.1| 92.0 ± 0.3|
| Crude protein    | 48.6 ± 0.7| 49.3 ± 0.5| 49.3 ± 0.4| 50.3 ± 0.7|
| Ether extract    | 18.3 ± 0.1| 17.7 ± 0.3| 18.0 ± 0.3| 18.0 ± 0.2|
| Ash              | 6.6 ± 0.3 | 6.6 ± 0.3 | 6.7 ± 0.3 | 6.7 ± 0.2 |
| Crude fibre      | 2.5 ± 0.4 | 2.7 ± 0.4 | 2.9 ± 0.2 | 2.2 ± 0.4 |
| N-free extract   | 24.0 ± 0.8| 23.7 ± 0.6| 23.1 ± 0.7| 22.8 ± 0.8|
| Energy           | 22.94 ± 0.45| 22.74 ± 0.30| 22.50 ± 0.28| 22.90 ± 0.29|

¹ Vitamin premix (values are in g/kg⁻¹ premix, except where units are given): retinol acetate (1,200,000 U); vitamin D₃ (600,000 U); α-tocopherol acetate, 30.0; vitamin K₃, 3.2; thiamin, 3.0; riboflavin, 4.0; pantothenic acid, 3.0; Ca-d-panthotenate, 14.0; niacin, 30.0; biotin, 0.2; folic acid, 1.0; vitamin B₁₂ (100 U); L-ascorbic acid, 40.0; inositol, 70.0; ethoxyquin, 15.0.

² Mineral premix (values are in g/kg⁻¹ premix): CaHPO₄ 2H₂O, 157; KH₂PO₄, 300.0; MgO, 11.54; MnO, 2.58; FeCO₃, 3.55; ZnO, 2.50; CuSO₄ 5H₂O, 0.15; KI, 0.09; Na₂SeO₃, 0.10; dextrins to 1000.0.

from the left back, 3 cm below the dorsal fin (Harpaz et al., 2003). Total lipids of diets and fish muscles were extracted according to the Folch method (1957). Fatty acid compositions were determined by gas chromatograph separation of fatty acid methyl esters, using a Thermo Finnigan (trace GC2000) gas chromatograph and an Omegawax Supelco 30 m x 0.32 mm column, with the operative conditions previously described by Lanari et al. (1999).

**Formulae and statistical analysis**

The formulae of the main performance and body trait variables are reported, respectively, as footnotes of Tables 4 and 5. Formulæ of Atherogenic index (AI) and Thrombogenic index (TI) were computed according to Ulbright and Southgate (1991; foot notes Table 3). Productive performances, carcass traits, whole body composition and muscle fatty acid contents were submitted to one-way analysis of variance. The means were compared using LSD test (Snedecor and Cochran, 1982).
Results

The main differences between single fatty acids in the diets can be observed for C12:0 (0-42.56 % t.a.) and C14:0 (6.92 – 16-74 % t.a.) (Table 2). Every 6 % additional rate of coconut oil in the diet caused a huge increase of SFA (from 25 to 75 % t.a.) with a subsequent reduction of monounsaturated and polyunsaturated fatty acids (Table 3). Thus diet D was characterized by 79.4 % SFA, 11.2 MUFA, and 9.35 % PUFA. The SFA/USFA ratio increased accordingly with the inclusion of coconut oil in the diet, from 38.2 (A) to 385 % (D) (Table 3). The n-3 series was affected to a great extent by dietary treatments, decreasing sevenfold, from 28.88 (A) to 4.10 % t.a. (D). AI increased ninefold: 0.64 (A) 5.89 (D) (Figure 1). The same trend was observed for TI, but to a lesser extent: from 0.24 (A) to 1.24 (D) (Figure 2).

All diets showed good palatability, indirectly

Table 2. Selected fatty acids in the experimental diets fed to rainbow trout (% total area)

| Diets | A     | B     | C     | D     | SEM  |
|-------|-------|-------|-------|-------|------|
|       |       |       |       |       | (12 df) |
| C10:0 | 0.00  |       |       |       |      |
| C12:0 | 0.00  | 2.67  |       | 5.00  | 5.37 |
| C14:0 | 6.92  | 11.89 | 16.15 | 16.74 | 0.46 |
| C16:0 | 18.64 | 15.00 | 12.08 | 11.99 | 0.30 |
| C16:1 n7 | 9.30 | 5.16 | 1.86 | 0.95 | 0.12 |
| C18:0 | 2.06  | 2.32  | 2.59  | 2.72  | 0.16 |
| C18:1 n9 | 10.31| 9.71 | 9.14  | 8.32  | 0.21 |
| C18:2 n6 | 2.64 | 1.88 | 0.86  | 0.33  | 0.42 |
| C18:3 n3 | 6.05 | 5.74 | 5.34  | 5.24  | 0.15 |
| C18:4 n3 | 1.42 | 0.96 | 0.55  | 0.50  | 0.07 |
| C20:1 n9 | 3.06 | 1.51 | 0.00  | 0.00  | 0.06 |
| C20:4 n6 | 6.08 | 3.38 | 1.24  | 0.68  | 0.13 |
| C20:5 n3 | 0.00 | 0.00 | 0.00  | 0.00  | -    |
| C22:1 n9 | 11.60| 6.36 | 1.39  | 1.34  | 0.39 |
| C22:6 n3 | 4.45 | 2.57 | 0.54  | 0.49  | 0.24 |
|       |       |       |       |       |      |

Means in the same row not sharing common superscript letters are significantly different. A, B, C, D: P< 0.01.

Figure 1. AI of the diet and in the muscle of rainbow trout fed increasing levels of refined coconut oil.

Columns not sharing a common superscript letter are significantly different. A, B : P < 0.01.

Figure 2. TI of the diet and of the muscle of rainbow trout fed increasing levels of refined coconut oil.
Table 3. Content of the main fatty acids classes, ratios and indices of the experimental diets fed to rainbow trout (% total area)

| Diets | A          | B          | C          | D          | SEM (12 df) |
|-------|------------|------------|------------|------------|-------------|
| SFA   | 27.63      | 53.54      | 75.86      | 79.38      | 0.69        |
| MUFA  | 37.44      | 25.22      | 14.33      | 11.27      | 1.03        |
| PUFA  | 34.93      | 21.24      | 9.81       | 9.35       | 0.43        |
| USFA  | 72.37      | 46.46      | 24.14      | 20.62      | 0.69        |
| (SFA/USFA)*100 | 38.18      | 115.23     | 314.33     | 385.08     | 0.11        |
| n-3   | 28.88      | 15.50      | 4.46       | 4.10       | 0.46        |
| n-6   | 6.05       | 5.74       | 5.34       | 5.24       | 0.15        |
| n-9   | 20.84      | 15.66      | 10.92      | 9.49       | 0.44        |
| n-3/n-6 | 4.77       | 2.70       | 0.84       | 0.78       | 0.11        |
| DHA/EPA | 1.03       | 1.05       | 1.84       | 1.69       | 0.23        |
| AI    | 0.64       | 2.60       | 4.84       | 5.89       | 0.12        |
| TI    | 0.48       | 0.49       | 1.18       | 1.13       | 0.13        |

Means in the same row not sharing a common superscript letters are significantly different. A, B, C, D: P < 0.01.

1 SFA: saturated fatty acids.
2 MUFA: monounsaturated fatty acids.
3 PUFA: polyunsaturated fatty acids.
4 USFA: unsaturated fatty acids.
5 AI (Atherogenic index): (C12+ 4*C14)+C16)/(n3+n6+MUFA).
6 TI (Thrombogenic index): (C14+ C16+ C18)/(0.5 MUFA) + (0.5 n-6) + (3* n-3) + (n-3/n-6).

Table 4. Main performances of rainbow trout fed diets with increasing levels of coconut oil

| Diets | A          | B          | C          | D          | SEM (12 df) |
|-------|------------|------------|------------|------------|-------------|
| Tank ration (%) ABW | 0.75       | 0.72       | 0.79       | 0.74       | 0.09        |
| Initial BW g | 242.09     | 241.9      | 244.3      | 242.4      | 4.78        |
| Final BW  " | 1128.7     | 1160.0     | 1074.7     | 1096.9     | 104.67      |
| Daily growth rate | 3.90       | 3.78       | 3.62       | 3.63       | 0.48        |
| SGR    | 0.662      | 0.678      | 0.639      | 0.653      | 0.04        |
| TGU (X1000) | 1.44       | 1.48       | 1.38       | 1.41       | 0.12        |
| FCI    | 1.36       | 1.35       | 1.48       | 1.39       | 0.14        |
| PER    | 1.55       | 1.51       | 1.38       | 1.41       | 0.12        |

Means in the same row not sharing a common superscript letters are significantly different. A, B, C, D: P < 0.01.

1 Tank ration: Daily feed (g)/(BWfin.(g) + BW•in. (g))/2.
2 SGR: Specific growth rate = [ln Weight fin.(g) - ln Weight•in.(g)] / 100 /days.
3 TGU: Thermal growth unit = vBWfin. (g) + vBW•in. (g) / Σ(Temp. * days).
4 Feed conversion index: Feed intake (g) / Fish weight gain (g).
5 PER: Protein efficiency ratio (g)/protein intake (g).
6 BW: Body weight.
### Table 5. Body traits and whole body composition (% WW, except for Energy: KJ/g^-1 fish) of rainbow trout fed diets with increasing levels of refined coconut oil.

| Diets | Beginning | A     | B     | C     | D     | SEM (56 df) |
|-------|-----------|-------|-------|-------|-------|-------------|
| K factor | 1.87      | 1.89  | 1.94  | 2.00  | 0.18  |
| HSI | 1.56      | 1.61  | 1.50  | 1.72  | 0.50  |
| GSI | 0.87      | 3.03  | 0.43  | 1.68  | 3.40  |
| VSI | 10.25     | 9.39  | 10.02 | 11.08 | 3.78  |
| Water | 69.3      | 64.29 | 65.30 | 64.21 | 63.47 | 2.87 |
| Crude protein | 16.9      | 18.27 | 18.76 | 18.06 | 18.96 | 2.41 |
| Crude fat | 10.4      | 15.04 | 14.31 | 15.00 | 16.21 | 2.88 |
| Ash | 2.70      | 2.00  | 2.00  | 2.16  | 2.02  | 0.20 |
| Energy | 7.73      | 9.29  | 9.49  | 9.87  | 10.68 | 0.96 |

Means in the same row not sharing the same superscript letters are significantly different.  a, b:  P < 0.05;  A, B, C:  P < 0.01

1 K factor : condition factor = Gross Weight (g) · 100 / Standard length ^1 (cm).
2 HSI : Hepatosomatic index = Liver weight (g) · 100 / Net fish weight (g).
3 GSI : gonado-somatic index = Gonads weight (g) · 100 / Net fish weight (g).
4 VSI : viscero-somatic index = [Viscera weight (g) – gonads (g)]·100 / Net fish weight (g).

### Table 6. Main fatty acids content (mg/g^-1 muscle) of the dorsal muscle of rainbow trout fed increasing levels of refined coconut oil.

| Diets | A     | B     | C     | D     | SEM (32 df) |
|-------|-------|-------|-------|-------|-------------|
| C10:0 | 0.08  | 0.08  | 0.29  | 0.23  | 0.16 |
| C12:0 | 2.01  | 2.10  | 6.77  | 5.21  | 3.10 |
| C14:0 | 2.12  | 2.13  | 4.66  | 3.62  | 1.82 |
| C16:0 | 5.27  | 5.21  | 7.04  | 5.55  | 2.51 |
| C16:1 n7 | 1.58 | 1.80  | 1.88  | 1.50  | 0.79 |
| C18:0 | 1.20  | 1.26  | 1.97  | 1.55  | 0.74 |
| C18:1 n9 | 5.16 | 5.46  | 8.46  | 6.69  | 3.36 |
| C18:1 n7 | 0.75 | 0.79  | 0.91  | 0.70  | 0.36 |
| C18:2 n6 | 2.04 | 2.10  | 3.52  | 2.49  | 1.37 |
| C18:3 n3 | 0.44 | 0.31  | 0.29  | 0.18  | 0.15 |
| C18:4 n3 | 0.48 | 0.32  | 0.19  | 0.10  | 0.20 |
| C20:1 n9 | 2.46 | 1.47  | 1.05  | 0.65  | 0.77 |
| C20:4 n6 | 0.21 | 0.17  | 0.27  | 0.22  | 0.10 |
| C20:5 n3 | 1.36 | 1.26  | 0.76  | 0.48  | 0.34 |
| C22:1 | 1.27  | 1.11  | 0.55  | 0.32  | 0.47 |
| C22:6 n3 | 6.45 | 5.18  | 4.82  | 2.95  | 2.18 |
| C24:1 n9 | 0.08 | 0.09  | 0.07  | 0.05  | 0.04 |

Total fatty acids (mg/g^-1 muscle) | 32.1 | 33.1 | 35.7 | 34.1 | 5.32 |

Means in the same row not sharing a common superscript letter are significantly different.  a,b:  P < 0.05;  A, B, C:  P < 0.01
confirmed by the same feeding levels (0.74 %) maintained by all groups during the entire experimental phase. Fish grew from an initial live weight of 242.9 g to more than 1 kg (Table 4). Daily weight gain exceeded 3.5 g d⁻¹.

Mortality was negligible: 3 specimens during the whole trial. The good general conditions of the fish stocks are indicated by growth variables (SGR varied from 0.639 to 0.678) and feed efficiency (average value: 1.39); PER ranged between 1.38 and 1.55.

The dietary treatments did not have a significant effect on the whole fish proximate composition: moisture (64.3 %), crude protein (18.5 %), crude fat (15.1 %) and ash (2 %) (Table 5). On the contrary, the fish energy content significantly increased with increasing coconut oil inclusion rates, from 9.29 (A) to 10.68 (D) KJ g⁻¹ a.s.

The total amount of fatty acids in fish muscle did not differ significantly among the treatments: 33.8 mg g⁻¹ tissue (Table 6). The content of single SFA: C10:0, C12:0 and C14:0 significantly increased in the muscle of RB trout fed diet C (P < 0.01), while the B treatment showed no difference compared to A (Table 6). Oleic and linoleic acids and also C16:0 in the RB trout muscle showed the same contents, irrespective of the dietary treatments (Table 6), while C18:4 n-3, C20:1 n-9, C22:1, EPA and DHA significantly decreased when the inclusion of coconut oil in the diet was higher than 6 % (Table 6). Observing the main fatty acid classes, no difference was evident for SFA, MUFA and PUFA, although the SFA tended to increase in the C and D treatments, and the SFA/USFA ratio almost doubled from A (52.9 %) to C and D (91.9 %, Table 7). The n-3 was the only series that varied in the dietary treatments, with a significant decrease (almost half) from diets A and B to D (7.76 vs 4.17) (Table 7). The strongest “conservative action” for DHA vs EPA in rainbow trout feeding diets C and D, caused a significant increase in the DHA/EPA ratio in their muscle (Table 7). On the other hand, the lower values for the DHA/AA ratio observed in fish muscle of C and D treatments depended only on the variation of DHA, AA being constant in all the experimental groups (Table 7). Both AI and TI significantly increased when coconut oil inclusion rates reached 12 % or more: the first from 0.48 (A) to 1.16 (C and D), the latter, to a lesser extent, varying from 0.27 (A,B) to 0.56 (C,D) and remaining far below 1 (Figures 1, 2; P< 0.01).
Discussion

The role of saturated fatty acids as energetic substrates has been mainly studied in the nutrition of terrestrial mammals (Amoresseau et al., 1989; Benevenga et al., 1989; Bozzolo et al., 1993), to which they are largely supplied, also to enforce the diet flavour. The use of coconut derived oils, particularly rich in saturated fatty acids, showed contrasting results in fish nutrition, but this is partly due to large phylogenetic differences among species and to different sizes of the test fish. In cold-water species, such as Salmonids, coconut oil was less studied because in the past the research had been focused on lipids of animal origin: beef tallow, pork lard or poultry oil (Yu et al., 1977; Reinitz, 1980; Yu and Sinnhuber, 1981; Greene and Selivonchick, 1990). Cowey (1993) first gave emphasis to the use of middle chain triglycerides (MCT) in fish nutrition and Olsen et al. (1998) recently reported that Arctic charr (Salvelinus alpinus) C12:0 is well "released" from coconut oil triacylglycerols and it is more efficiently absorbed than longer saturated fatty acids in the pyloric caeca and gut.

Netatipour et al. (1989) and Mustafa et al. (1991) demonstrated that commercial diets with a supplementation of MCT tended to improve the quality of fish carcass, feed conversion efficiency and PER in ayu (Plecoglossus altivelis altivelis, Temminck and Schlegel, 1846). On the other hand, the inclusion of coconut oil or MCT in diets for channel catfish (Ictalurus punctatus) and Nile tilapia (Oreochromis niloticus) did not assure the same performance as fish oil in the former species (Stickney and Andrews, 1972) or soybean oil and corn oil in the latter (Takeuchi and Watanabe, 1983). Moreover, coconut oil was considered an efficient lipid source for African catfish (Heterobranchus longifilis), as reported by Legendre et al. (1995) and it seems to be well metabolised by red drum juveniles (Sciaenop ocellatus) (Craig and Gatlin, 1995). A similar trend was found by Fontagné et al. (1999), studying the effects of coconut oil, tricaprylin and triolein on the growth and survival of common carp (Cyprinus carpio) larvae, with the best results obtained with coconut oil and triolein. This trial confirms that the RB trout can easily adapt to the whole spectrum of dietary fatty acids, for its maintenance and growth, including saturated fatty acids C10:0-C18:0. Cowey (1993) suggested these fatty acids as an interesting energy supply for fish, being preferentially catabolised before unsaturated f.a.

This trial confirms that the fatty acid composition of RB trout muscle is affected by dietary lipids, although less than expected. In fact, the metabolism of the species counteracts the extreme fatty acid profiles of the diet and the AI and TI varied less than dietary indices, as can be seen in Figures 1 and 2. Even if the dietary SFA reached 80 % of total f.a., their absolute amounts in the muscle increased from 11 to 20 mg g⁻¹ muscle, which is less than double. Another important aspect to consider is that the total amount of fatty acids in the RB trout muscle was close to 3.4 % of the fresh tissue, irrespective of the lipid source administered. This is another point to consider when the quality of fish flesh is the concern, because, depending on the species, fat could be "stored" in the muscle (instead of the liver or the visceral fat) and this phenomenon should be taken into consideration during fish diet formulation.

Conclusions

The diet which was more balanced, as far as lipid ingredients were concerned: diet B, gave the same performance and single fatty acids series and indices in RB trout muscle as the control (fed only with fish oils as lipid ingredients). The trend of the fish performance was slightly worse with the extreme diets (12-13 % coconut oil), while TI and AI of muscle fatty acids doubled, with respect to the diet with fish oil. In particular AI was lower than the average values commonly observed in terrestrial animals: 1.33 lamb meat, 1.06 bull meat, 1.37 pork meat (Ulbricht and Southgate, 1991).

In conclusion, it should be emphasized that refined coconut oil can be another interesting lipid source for RB diets and it can be supplied up to 6 % in the diet without having a negative effect on fish performance and muscle fatty acid profile.
REFERENCES

AMORESSEAU, B., VERMOREL, M., THERIEZ, M., VEZINHET, A., 1989. Effects of substitution of tricaprylin or coconut oil for tallow in milk replacers offered to preruminant lambs. Ann. Zootech. 38:49-50.

AOAC, 1995. Official Methods of Analysis. 16th ed. AOAC International, Arlington, VA, USA.

BENEVenga, N.J., STEINMAN – GOLDSWORTHy, J.K., CRENSHAW, T.D., ODELE, J., 1989. Utilization of medium – chain triglycerides by neonatal piglets: I. Effects on milk consumption and body fuel utilization. J. Anim. Sci. 67:331-339.

BIMBO, A.P., 1990. Production of fish oil. In: M.E. COWEY, C.B., 1993. Some effects of nutrition on flesh Bozzolo, G., Bouillier-Oudot, M., Candau, M., 1993. AOAC, 1995. Official Methods of Analysis. 16th ed.

CRAIG, S.R., GATLIN, D.M. III, 1995. Coconut oil and FOLCH, J., LEES, M., STANLEY, G.H.S., 1959. A simple FAO, 2002. Use of fish meal and fish oil in aquafeeds: Crae, G., 1980. Acceptability of animal fat in diets for Atlantic salmon in relation to fish size: growth, feed utilization and slaughter quality. Aquacult. Nutr. 3:115-126.

EINEN, O., ROEM, A.J., 1997. Dietary protein/energy ratios for Atlantic salmon in relation to fish size: growth, feed utilization and slaughter quality. Aquacult. Nutr. 3:115-126.

FAO, 2002. Use of fish meal and fish oil in aquafeeds: further thoughts on the fish meal trap. M.B. New and U.N. Wijkström (eds.). FAO Fisheries Circular 57:2327-2331.

FOLCH, J., LEES, M., STANLEY, G.H.S., 1959. A simple method for the isolation and purification of total lipids from animal tissue. J. Biol. Chem. 232:38-59.

FONTAGNÉ, S., PRUSZYNSKI, T., CORRAZE, G., BERGOT, P., 1999. Effect of coconut oil and tricaprylin vs triolein on survival, growth and fatty acid composition of common carp (Cyprinus carpio L.) larvae. Aquaculture. 179:241-251.

GREENE, D.H.S., SELIVONCHUK, D.P., 1990. Effects of dietary vegetable, animal and marine lipids on muscle lipid and hematology of rainbow trout (Oncorhynchus mykiss). Aquaculture. 89:165-182.

HARMACO, S., GUTMAN, L., DRABKIN, V., GELMAN, A., 2003. Effects of herbal essential oils used to extend the shelf life of freshwater reared Asian sea bass fish (Lates calcarifer). J. Food Protect.

LANARI, D., POLI, B.M., BALLEGRAZZI, R., LUPI, P., D’AGARO, E., MECATTI, M., 1999. The effects of dietary fat and NFE levels on growing European sea bass (Dicentrarchus labrax, L.). Growth rate, body and fillet composition, carcass traits and nutrient retention efficiency. Aquaculture. 179:351-364.

LEGENDRE, M., BERBOURCHU, N., CORRAZE, G., BERGOT, P., 1995. Larval rearing of an African catfish Heterobranchus longifilis (Teleostei, Claridae): effect of dietary lipids on growth, survival and fatty acid composition of fry. Aquat. Living Resour. 8:355-363.

MURITICHAN, D.S., HARDY, R.W., IWAOKA, W.T., 1981. Linseed oil and animal fat as alternative lipid sources in dry diets for chinook salmon (Oncorhynchus tschawytscha). Aquaculture. 25:161-172.

MUSTAFA, M.G., NAKAGAWA, H., OHYA, S., SHIMIZU, T., HORIKAWA, Y., YAMAMOTO, S., 1991. Effects of various level of dietary medium chain triglycerides on growth and lipid reserve in Ayu. Nippon Suisan Gakka. 57:2327-2331.

NETATIPOUR, G.R., NISHINO, H., NAKAGAWA, H., 1989. Availability of Medium Chain Triglycerides as Feed Supplementation in Ayu Plecoglossus altivelis (Pisces). pp 233 – 244 in Proc. 3rd Int. Symp. on Feeding and Nutrition in Fish, Tobá, Japan.

OLSEN, R.E., HENDERSON, R.J., RINGO, E., 1998. The digestion and selective absorption of dietary fatty acids in Arctic char, Salvelinus alpinus. Aquacult. Nutr. 4:13-21.

OLSEN, R.E., MILLW, W., TORESEN, R., VALDEMARSEN, J.W., TORRISEN, O.J., 2004. New marine feed resources for aquafeeds. Page 71 (abstr.) in Proc. 11th Int. Symp. on Nutrition and Feeding in Fish, Phuket Island, Thailand.

REINITZ, G., 1989. Acceptability of animal fat in diets for rainbow trout at two environmental temperatures. Prog. Fish Cult. 42:218-222.

REINITZ, G., YU, T.C., 1981. Effects of dietary lipids on growth and fatty acid composition of rainbow trout (Salmo gairdneri). Aquaculture. 22:359-366.

SARGENT, J.R., TOCHER, D.R., BELL, J.G., 2002. The lipids. In : J.E. Halver and R.W. Hardy (eds.) Fish nutrition. 3rd ed. Academic Press, San Diego, CA, USA, pp 181-257.

SNEDECOR, P., COCKRAN, W.G., 1982. Statistical Methods. The Iowa State University Press, Ames, IA, USA.

STICKNEY, R.R., ANDREWS, J.W., 1972. Effects of Dietary Lipids on Growth, Food Conversion, Lipid and Fatty Acid Composition of Channel Catfish. J. Nutr. 102:249-258.

TAKECHI, S.T., WATANABE, T., 1983. Dietary lipids suitable for the practical feed of Tilapia nilotica.
BALLESTRAZZI et al.

B. Jpn. Soc. Sci. Fish. 49:1361-1365.
ULBRIGHT, T.V.L., SOUTHGATE, D.A.T., 1991. Coronary heart disease: seven dietary factors. Lancet. 338:985-990.
YU, T.C., SINNHUBER, R.O., PUTNAM, G.B., 1977. Use of swine fat as an energy source in trout rations. Prog. Fish Cult. 39:95-97.
YU, T.C., SINNHUBER R.O., 1981. Use of beef tallow as an energy source in coho salmon (Oncorhynchus kisutch) rations. J. Fish. Res. Board Can. 38:367-370.