Spanish Journal of Agricultural Research
20 (4), e0609, 11 pages (2022)
eISSN: 2171-9292
https://doi.org/10.5424/sjar/2022204-18977
INIA-CSIC

RESEARCH ARTICLE

OPEN ACCESS

Effect of dietary vegetable lipid sources on the growth performance and whole-body fatty acid profile of giant trahira, *Hoplias lacerdae*

Ana L. Salaro[1], Thiago R. A. Felipe[1], Cristiana L. S. Carneiro[1], Jener A. S. Zuanon[1], Cephora M. Sabarense[2], Antônio P. S. Carneiro[3], Wilson M. Furuya[4], Galileu C. Veras[5]and Daniel A. V. Campelo[6]

[1]Dept. de Biologia Animal, Universidade Federal de Viçosa, Av. Peter Henry Rolfs s/n, 36570-900 Viçosa, MG, Brazil. [2]Dept. de Nutrição, Universidade Federal de Juiz de Fora, Rua José Lourenço Kelmer s/n, 36036-900 Juiz de Fora, MG, Brazil. [3]Dept. de Estatística, Universidade Federal de Viçosa, Av. Peter Henry Rolfs s/n, 36570-900 Viçosa, MG, Brazil. [4]Dept. de Zootecnia, Universidade Estadual de Ponta Grossa, Av. Gral. Carlos Cavalcanti 4748, Uvarans, 84030-900 Ponta Grossa, PR, Brazil. [5]Dept. de Zootecnia, Universidade Federal de Minas Gerais, Escola de Veterinária, Laboratório de Aquacultura, Av. Antônio Carlos, 6627, 31275-013 Belo Horizonte, MG, Brazil. [6]Inst. de Estudos Costeiros, Universidade Federal do Pará, Alameda Leandro Ribeiro s/n, 68600-000 Bragança, PA, Brazil.

Abstract

Aim of study: To evaluate which vegetable lipid source promotes better growth performance, whole-body composition and fatty acid profile for juvenile giant trahira (*Hoplias lacerdae*).

Area of study: Fish Nutrition Laboratory of the University of Viçosa (UFV), MG, Brazil.

Material and methods: A 50-day feed trial with four treatments, consisting of diets containing different vegetable lipid sources (canola, linseed, soybean or olive oil), was conducted with juveniles of 4.76 ± 0.50 cm and 1.97 ± 0.20 g.

Main results: There were no effects of vegetable lipid sources on growth performance. Fish fed diets containing canola oil had higher body lipid deposition and fish fed with linseed oil had lower body lipid content (up to -19.29%) than fish from other treatments. Fish fed canola oil showed lower proportions of saturated fatty acids (up to -11.27%) in the body. Fish fed diets containing soybean oil and linseed oil showed the highest percentages of linoleic and α-linolenic fatty acids, respectively. Fish fed diets containing soybean and linseed oils also had higher total polyunsaturated fatty acids content (up to +81.14%). Fish fed diets containing linseed oil had lower content of monounsaturated fatty acids (up to -58.59%) and higher content of docosahexaenoic (up to +175%) and eicosapentaenoic (not detectable to detectable) acids.

Research highlights: Juveniles of giant thraira can alter the whole-body fatty acid profile due to their ability to desaturate and elongate the n3 and n6 series fatty acids. Linseed oil was identified as lipid source for this fish species.

Additional key words: Aquaculture; carnivorous fish; essential fatty acids; Neotropical fish; vegetable oils

Abbreviations used: ARA (arachidonic acid); DHA (docosahexaenoic acid); EPA (eicosapentaenoic acid); LA (linoleic acid); LC-PUFA (Long chain polyunsaturated fatty acids); LNA (α-linolenic acid), MUFA (monounsaturated fatty acids), PUFA (polyunsaturated fatty acids), SFA (saturated fatty acids).

Citation: Salaro, AL; Felipe, TRA; Carneiro, CLS; Zuanon, JAS; Sabarense, CM; Carneiro, APS; Furuya, WM; Veras, GC; Campelo, DAV (2022). Effects of dietary vegetable lipid sources on the growth performance and whole-body fatty acid profile of giant trahira, *Hoplias lacerdae*. Spanish Journal of Agricultural Research, Volume 20, Issue 4, e0609. https://doi.org/10.5424/sjar/2022204-18977

Received: 09 Nov 2021. **Accepted:** 3 Nov 2022.

Funding agencies/institutions	Project / Grant
National Council of Scientific and Technological Development (CNPq)	304975/2017-6
Coordination for the Improvement of Higher Education Personnel (CAPES)	Financing Code 001
Minas Gerais State Foundation for Research Aid (FAPEMIG)	2070.01.0004720/2021-22

Competing interests: The authors have declared that no competing interests exist.

Correspondence should be addressed to Ana L. Salaro: salaro@ufv.br

Introduction

The giant trahira, *Hoplias lacerdae* (Ribeiro, 1908), is a freshwater Neotropical fish species with wide geographical distribution in Brazil, being found in lotic water environments such as streams and waterfalls (Oyakawa *et al*., 2009; Loro & Luz, 2020). This species has great potential for aquaculture (Luz *et al*., 2002; Luz & Portella, 2005; Veras *et al*., 2010), mainly due to the rapid growth and high quality of fish meat (Luz *et al*., 2002; Luz & Portella, 2005). Furthermore, studies related to productive aspects of this species revealed that it adapts well to captive conditions and accepts processed diets, as long as the fingerlings are previously conditioned (Luz *et al*., 2001; Salaro *et al*., 2003; 2008; 2012; Nogueira *et al*., 2005). Regarding the nutrition of this species, the protein and energy requirements (Veras *et al*., 2010) and the optimal level of L-glutamine in the diet (Ramos *et al*., 2022) have already been determined. Juveniles of giant trahira fed with soybean oil as vegetable lipid source were able to deposit long chain polyunsaturated fatty acids (LC-PUFAs) in their carcass/musculature, which indicates that this species is capable of bioconversion of 18C fatty acids (Kasai *et al.*, 2011).

Among the macronutrients that make up the animal diet, lipids are the main source of energy and fatty acids, especially in the case of carnivorous species (Cyrino *et al*., 2000; Sargent *et al*., 2002; Tocher, 2003). Therefore, its supply is essential for growth, reproduction, neural and visual development (Balfry & Higgs, 2001) and fish health (Turchini *et al*., 2009). A deficiency or excess of lipids in the diet can lead to slower fish growth or the accumulation of lipids throughout the whole-body, compromising the quality of the fish meat.

LC-PUFA of the n6 and n3 series are considered essential for fish, especially the biologically active forms, arachidonic acid (ARA 20:4 n6), eicosapentaenoic acid (EPA 20:5 n3) and docosahexaenoic acid (DHA 22:6 n3) (Turchini *et al*., 2009; 2011). In general, marine and cold-water fish species must obtain these fatty acids directly from the diet since evolutionarily, due to the high environmental availability, some fish species have lost the ability to synthesize LC-PUFA from its precursors, the linoleic (LA; 18:2 n6) and α-linolenic acids (LNA; 18:3 n3) (Sargent *et al*., 2002). For this reason, its production is highly dependent on lipids sources rich in LC-PUFA, such as fish oil (Trushenski & Rombenso, 2020). On the other hand, a large part of tropical freshwater fish species can convert LA and LNA, present in vegetable oils, into LC-PUFA and, therefore, have the advantage of making good use of these dietary lipid sources (Oliva-Teles *et al*., 2015; Alhazzaa *et al*., 2018).

Among the vegetable lipid sources, soybean, canola and olive oils rich in AL and linseed oil rich in LNA stand out (Zambiazi *et al.,* 2007; Kostik *et al.,* 2013). Therefore, since the fatty acid profile of fish can reflect the fatty acid profile of the diet, the supply of different plant lipids in the diets can influence the lipid profile of the fish's whole-body (Torstensen *et al*., 2005; Nanton *et al*., 2007; Turchini *et al*., 2009), changing the nutritional quality of fish meat and bringing benefits to fish farming. Therefore, this study aimed to evaluate which vegetable lipid source promotes better growth performance, whole-body composition and fatty acid profile for juvenile giant trahira (*H. lacerdae*).

Material and methods

Ethics statement

This experiment was carried out at the Fish Nutrition Laboratory of the Fish Farm Teaching, Research and Extension Unit (UEPE-Piscicultura) of the Animal Biology Department of the Federal University of Viçosa (UFV), Viçosa, Minas Gerais, Brazil. In addition, it was approved by the Ethics Committee on the Use of Production Animals (CEUAP/UFV) of the UFV (protocol nº 035/2020).

Experimental design and diets

A completely randomized design experiment with four treatments and five replicates was performed. The treatments consisted of four isonitrogenous (422.6 g kg^{-1}) and isoenergetic (1891.0 MJ kg^{-1}) diets, formulated with different vegetable lipid sources, soybean, canola, linseed or olive oil (Mundo dos Óleos LTDA, Brasília, DF, Brazil) and containing 138.82 g kg^{-1} of total lipids (Table 1). Experimental diets were formulated following the chemical composition of ingredients described by Rostagno *et al*. (2005). Dietary protein and lipid levels were based on studies carried out by Veras *et al*. (2010) and Faria *et al*. (2019).

The ingredients were finely ground, mixed, moistened with water (50°C) and pelleted. Then, the diets were dried in a forced air oven at 50°C for 24 h, crushed in a manual mill and manually passed through granulometric sieves (Tecnal, Piracicaba, SP, Brazil) to obtain pellets sizes proportional to the mouth size of the fish (2 mm).

Samples of the diets were collected for fatty acid composition analysis using a gas chromatograph (Shimadzu GC-17A, Kyoto, Japan) equipped with a fused silica SP-2560 (bis-cyanopropil polysiloxane) chromatography column (Supelco Inc., Bellefonte, PA, USA) 100 m long and with a 0.25 mm internal diameter (Table 2). The fatty acid profiles of the experimental diets were determined at the Laboratory of Food Analysis, Department of Nutrition and Health, UFV.

Fish and culture conditions

The fish used in this study were obtained from the spawning of breeders housed in culture tanks of the Fish

Table 1. Formulation and chemical composition of experimental diets according to different dietary vegetable lipid sources.

Ingredient (g kg^{-1})	Dietary vegetable lipid sources			
	Soybean oil	**Canola oil**	**Linseed oil**	**Olive oil**
Soybean meal	170.0	170.0	170.0	170.0
Corn gluten	290.0	290.0	290.0	290.0
Wheat meal	90.0	90.0	90.0	90.0
Meat meal-45 [1]	350.7	350.7	350.7	350.7
Cellulose	6.0	6.0	6.0	6.0
Soybean oil	80.0	-	-	-
Canola oil	-	80.0	-	-
Linseed oil	-	-	80.0	-
Olive oil	-	-	-	80.0
L-lysine	6.0	6.0	6.0	6.0
DL- methionine	1.5	1.5	1.5	1.5
Vitamin C [2]	0.6	0.6	0.6	0.6
Min. and vit. supplement [3]	5.0	5.0	5.0	5.0
BHT [4]	0.2	0.2	0.2	0.2
Chemical composition (g kg^{-1}) [5]				
Gross energy (MJ kg^{-1})	1890.0	1910.0	1916.0	1931.0
Crude protein	418.9	423.4	428.7	419.4
Crude fiber	30.1	32.3	35.0	31.5
Total lipids	137.5	139.2	136.6	142.0
Total calcium	51.0	52.2	51.5	53.4
Total phosphorus	24.8	26.8	21.1	25.8
Lysine	18.7	18.2	17.4	17.9
Methionine	8.1	9.0	8.6	7.9

[1] Grupo Patense, Patos de Minas, MG, Brazil. [2] Ascorbil-2-monophosphate with 35% activity principle. [3] Mineral and vitamin supplement with guaranteed levels: vitamin A, 16,000 UI; vitamin D, 4,500 UI; vitamin E, 250 mg; vitamin K, 30 mg; vitamin B1, 32 mg; vitamin B2, 32 mg; vitamin B12. 32 mcg; vitamin B6. 32mg; vitamin C, zero; panthotenic acid. 80 mg; niacin, 170 mg; biotin, 10 mg; folic acid, 10 mg; choline, 2,000 mg; cobalt, 0.5 mg; copper, 20 mg; iron, 150 mg; iodide, 1 mg; manganese, 50 mg; selenium, 1 mg; zinc, 150 mg; antioxidative additive, 150 mg. [4] Butylated hydroxytoluene, antioxidant. [5] Values determined according to the AOAC (2000)

Farm Teaching, Research and Extension Unit (UEPE-Piscicultura) of the Animal Biology Department of the Federal University of Viçosa (UFV) and previously trained to accept processed diets following the methodology proposed by Luz *et al.* (2002) and adapted by Kasai *et al.* (2011).

Giant trahira (*H. lacerdae*) juveniles approximately three months old, with an initial length of 4.76 ± 0.50 cm and weight of 1.97 ± 0.20 g (mean ± SD), were selected and distributed in 20 aquariums (35 × 30 × 14 cm) blue polyethylene containing 7 L of water, at the density of eight fish per aquarium. The aquariums were arranged in a semi-static system, with 80% water volume renewal every three days, with constant aeration and biological filter. All aquariums were covered with plastic screens to prevent fish escape. The laboratory was maintained in photoperiod of 12 h through fluorescent lamps (60 W) and analog timer. Fish were fed the experimental diets until apparent satiation, three times a day (8:00, 13:00 and 17:00 hours) for 50 days.

During the experimental period, the water temperature was maintained at 26 ± 1.0°C (mercury thermometer) and the dissolved oxygen at 7.5 mg L^{-1} (multiparameter YSI-550a, Life Science, Greene, MS, USA), while pH and unionized ammonia remained at around 6.8 and 0.0 mg L^{-1} respectively (Labcon® analysis kits, Florianópolis, SC, Brazil).

Growth performance

At the end of the experiment, all fish from each aquarium (N=40 per treatment) were counted and weighed on

Table 2. Formulation and chemical composition of experimental diets according to different dietary vegetable lipid sources.

Fatty acid (%) [1]	Dietary vegetable lipid sources			
	Soybean oil	Canola oil	Linseed oil	Olive oil
C16:0	15.37	8.98	6.67	14.87
C18:0	4.56	0.97	2.22	6.43
∑SFA	19.94	9.96	8.15	21.30
C16:1	nd	nd	nd	1.14
C18:1 n9	33.41	63.24	27.80	60.51
∑MUFA	33.41	63.24	27.80	61.65
C18:2 n6 LA	44.60	24.47	15.62	16.06
C18:3 n3 LNA	2.05	2.34	48.44	0.99
LNA/LA	0.05	0.10	3.10	0.06
∑PUFA	46.65	26.80	64.06	17.05

[1] ∑SFA: total saturated fatty acids. ∑MUFA: total monounsaturated fatty acids. LA: linoleic acid. LNA: linolenic acid. ∑PUFA: total polyunsaturated fatty acids. nd: non-detectable at the level of 0.05%

a precision scale (model MB45 Toledo® 0.01 g, São Bernardo do Campo, São Paulo, Brazil) and measured to evaluate growth performance parameters. The following indices were calculated:

Length gain (cm) = final length (g) - initial length (cm);

Weight gain (g) = final weight (g) - initial weight (g);

Specific growth rate (%) = [(ln final weight - ln initial weight)/ 50 days] × 100;

Feed intake (*g fish*$^{-1}$) = amount of food consumed (g)/ number of fish;

Feed conversion rate = amount of food consumed (g)/ weight gain (g);

Survival rate (%) = (final number of fish/initial number of fish) × 100.

Chemical composition and fatty acid profile

The chemical composition of diets and whole-body of fish (dry matter, ash, crude protein, crude lipids and crude energy) were determined according to the AOAC (2000). The carcasses of three fish from each aquarium were previously grouped (N=5 per treatment), ground in a blender and homogenized. The carcass was considered fish without scales and viscera (stomach, intestine, gonads, heart, liver, gall bladder and swim bladder). Moisture was made by constant drying in an oven at 110°C until weight. The ash was obtained by incinerating the samples in a muffle furnace at 600°C for 3 h. The Kjeldahl method (N × 6.25) was used for crude protein analysis. Gross energy was measured by burning as a sample in a bomb calorimeter. Lipids analysis followed the Folch *et al*. (1957) method, and the fatty acid derivatization reaction followed the previously established method by IUPAC (1987). The fatty acid profile was obtained using a gas chromatograph (Shimadzu GC-17A, Kyoto, Japan) equipped with a chromatographic column of fused silica (Agilent J&W DB-WAX 122-7032, Santa Clara, CA, USA) and an ionization detector flame. The parameters used in the program were: detector temperature (240°C), injector temperature (240°C) and column temperature with heating at 10°C min^{-1} from 180 to 240°C, kept at this temperature for 10 min. Nitrogen was used as the carrier gas with a column flow of 0.6 mL min^{-1} and a linear velocity of 14 cm s^{-1}, with a total flow of 52 mL min^{-1} and a column pressure of 167 kPa, split 1:75. The chemical composition and lipid profile were performed at the Laboratory of Food Analysis of the Department of Animal Science and the Department of Nutrition of the UFV, respectively.

Statistical analysis

Statistical analyses were performed using software R, version 2.7.1 (São Paulo, SP, Brazil). Data were submitted to the Shapiro-Wilk test to verify the normality of the errors and to the Bartlett test to verify the homogeneity of the variances. The effects of dietary supplementing with different vegetable lipids sources were evaluated by analysis of variance (ANOVA) and by the Scott-Knott test, a procedure of means grouping, at 5% of significance.

Results

Growth performance

During the feeding trial, no aggressive behavior or cannibalism was observed among fish fed with different die-

Table 3. Growth performance parameters (means ± SD) of juvenile giant trahira (*Hoplias lacerdae*) fed with different dietary vegetable lipid sources (N=5).

Performace	Dietary vegetable lipid sources				
	Soybean oil	Canola oil	Linseed oil	Olive oil	CV (%)
Weight gain (g)	1.85 ± 0.37	2.25 ± 0.42	2.02 ± 0.27	2.30 ± 0.40	17.51
Length gain (cm)	1.95 ± 0.31	2.34 ± 0.59	2.06 ± 0.26	2.13 ± 0.30	18.25
Specific growth rate (% day^{-1})	1.31 ± 0.20	1.51 ± 0.15	1.41 ± 0.12	1.54 ± 0.20	11.88
Feed intake (g $fish^{-1}$)	1.82 ± 0.45	2.14 ± 0.10	2.09 ± 0.23	2.27 ± 0.23	10.43
Feed conversion	0.99 ± 0.11	0.95 ± 0.07	1.04 ± 0.04	0.99 ± 0.06	7.26
Survival rate (%)	100.00	100.00	100.00	100.00	0.00

CV= coefficient of variation. Mean values in the same row with different superscript letters are significantly different (p>0.05).

tary vegetable lipid sources. Fish from different treatments showed good acceptance of all experimental diets and ingestion occurred immediately after diet provision, with no signs of rejection.

Dietary vegetable lipid sources tested did not affect weight gain, length gain, specific growth rate, feed conversion rate and survival rate of fish (Table 3).

Whole-body chemical composition

The whole-body composition of the fish was directly affected by the vegetable lipid sources evaluated. Fish fed soybean and linseed oil had higher carcass moisture contents than fish fed with canola or olive oil. In addition, fish fed with linseed oil had lower total lipid content, and fish fed diets containing canola oil had higher total lipid deposition. There was no influence of the lipid source on the crude protein and ash contents of fish whole-body (Table 4).

Fatty acid profile

The different dietary vegetable lipid sources influenced fish's whole-body fatty acid profile. Fish fed diets containing linseed and soybean oils had higher proportions of stearic acid (C18:0). However, fish fed diet supplemented with olive oil showed lower stearic fatty acid content. Regarding the total saturated fatty acids (∑SFA), fish fed the diets containing linseed and soybean oils showed similar values, as the fish fed canola oil had the lowest value for the ∑SFA. The highest values for oleic acid (C18:1 n9) were observed in fish fed diet supplemented with olive oil, followed by those fed diets with canola, soybean and linseed oils, respectively (Table 5).

Fish fed diets containing soybean and linseed oils showed higher proportions of total polyunsaturated fatty acids (∑PUFA), with no differences between them. However, they differed significantly from the fish fed with olive and canola oils. Among the PUFA, the highest percentage of LA was found in fish fed the diet containing soybean oil, which was significantly different from the percentages found in fish fed the other diets. The values of LA found in fish fed diets containing canola oil and linseed oil were similar, differing from the fish fed diets containing olive oil, which showed the smallest amount of this fatty acid compared to the other diets. The fish whole-body LNA differed significantly between the treatments. The decreasing order of treatments were diets containing linseed, canola, soybean and olive oils, respectively. Noteworthy, fish fed diet containing linseed oil showed a higher proportion of DHA, which was significantly different from the other

Table 4. Whole-body chemical composition (means ± standard deviations) of juvenile giant trahira (*Hoplias lacerdae*) fed with different dietary vegetable lipid sources (N=5).

Parameters (% wet matter)	Dietary vegetable lipid sources				
	Soybean oil	Canola oil	Linseed oil	Olive oil	CV (%)
Moisture	75.49 ± 0.09a	74.50 ± 0.07c	75.36 ± 0.12a	75.19 ± 0.11b	0.25
Crude protein	15.67 ± 0.16	15.63 ± 0.26	15.67 ± 0.29	15.53 ± 0.18	2.34
Total lipids	4.77 ± 0.09b	5.34 ± 0.14a	4.31 ± 0.07c	4.70 ± 0.05b	1.18
Ash	4.54 ± 0.05	4.51 ± 0.05	4.58 ± 0.10	4.50 ± 0.04	1.50

CV= coefficient of variation. Mean values in same row with different superscript letters are significantly different by Scott-Knott method (p<0.05).

Table 5. Fatty acid composition (means ± standard deviations) of juvenile giant trahira (*Hoplias lacerdae*) fed with different dietary vegetable lipid sources (N=5)

Fatty acids (% total lipids)[1]	Dietary vegetable lipid sources				CV (%) [2]
	Soybean oil	Canola oil	Linseed oil	Olive oil	
C14:0^{ns}	0.71 ± 0.03	0.64 ± 0.02	0.63 ± 0.01	0.61 ± 0.06	5.58
C16:0	16.46 ± 0.58a	14.18 ± 0.13c	15.17 ± 0.19b	15.91 ± 0.11a	2.04
C18:0	8.14 ± 0.33a	6.97± 0.03b	8.15 ± 0.06a	6.42 ± 0.12c	2.43
∑SFA	25.55 ± 1.02a	22.67 ± 0.13c	24.69 ± 0.14a	23.98 ± 0.49b	2.37
C18:1 n9	31.44 ± 1.10c	42.65 ± 0.62 b	28.73 ± 0.12 d	46.89 ± 0.48 a	1.81
C20:1 n9^{ns}	0.63 ± 0.04	1.03 ± 0.01	0.53 ± 0.01	0.83 ± 0.002	34.98
∑MUFA	33.88 ± 1.18c	45.55 ± 0.67b	31.27 ± 0.24d	49.59 ± 0.86a	2.02
C18:2 n6 LA	22.61 ± 0.91a	15.36 ± 0.29b	14.93 ± 0.08b	12.19 ± 0.16c	2.99
C18:3 n3 LNA	1.40 ± 0.06c	1.53 ± 0.02b	11.90 ± 0.12a	0.53 ± 0.01d	11.90
C20:4 n6 ARA	nd	nd	nd	nd	nd
C20:5 n3 EPA	nd	nd	0.68 ± 0.09	nd	nd
C22:6 n3 DHA	2.53 ± 0.32b	2.41 ± 0.11b	4.18 ± 0.18a	1.52 ± 0.02c	7.16
LNA/LA	0.06 ± 0.01b	0.10 ± 0.02b	0.80 ± 0.01a	0.04 ± 0.00c	3.95
∑PUFA	37.17 ± 1.39a	26.60 ± 0.24b	36.93 ± 0.26a	20.52 ± 0.26c	2.41

[1] ns = not significant (p>0.05). ∑SFA: total saturated fatty acids. ∑MUFA: total monounsaturated fatty acids. LA: linoleic acid. LNA: linolenic acid. ARA: arachidonic acid. EPA: eicosapentaenoic acid. DHA: docosahexaenoic acid. ∑PUFA: total polyunsaturated fatty acids. [2] CV=coefficient of variation. Mean values in same row with different superscript letters are significantly different by Scott-Knott method (p<0.05). nd: non-detectable by level of 0.05%

treatments. Additionally, fish fed diets containing soybean and canola oils had similar proportions of DHA. The lowest values were found in fish fed the diet supplemented with olive oil. EPA was detected only on the fish that receive diets containing linseed oil and the ARA was not detectable in any of the fish (Table 5).

Discussion

The present study revealed that using different vegetable lipid sources in diets for giant trahira did not lead to significant changes in fish feed intake. Our results differ from those observed in other studies, which revealed a decrease in fish feed consumption when they were fed diets containing linseed oil exclusively as a lipid source. For example, silver catfish (*Rhandia quelen*) fingerlings fed diets containing 16.7 to 50 g kg^{-1} of linseed oil showed a reduction of up to 26% in consumption, compared to fish fed diets containing corn or fish oil (Vargas *et al.*, 2008). The same happened with juvenile silver barb (*Puntius gonionotus*), which showed a linear decrease in consumption as the levels of linseed oil in the diet increased from 30 to 90 g kg^{-1} until reaching the total replacement of fish oil (Nayak *et al.*, 2017). All these authors related that the reduction in fish feed intake is probably due to the less palatability of linseed oil. However, for giant trahira juveniles, even when fed diets containing 80 g kg^{-1} of linseed oil, the fish did not show feed intake differences compared to fish fed with soybean, canola or olive oils. This evidences a prompt acceptance of diets by fish, indicating that the vegetable lipid sources evaluated did not influence the palatability of the diets. These results may explain the absence of cannibalism and aggressive behaviors commonly observed in carnivorous fish species.

The use of different vegetable lipids sources can cause different effects on lipid deposition in fish (Bell *et al.*, 2003). It is possible that the higher and the lower level of whole-body lipids in fish fed dietary canola oil and linseed oil, respectively, was related to the regulation of gene expression and the enzyme activity involved in lipid metabolism (Castro *et al.*, 2016b). The oxidation or deposition of lipids in tissues depends on each fatty acid's dietary source and its function in the fish body. The lipogenesis and fatty acids bioconversion pathways are regulated by the dietary lipid source (Castro *et al.*, 2016b). In the present study, fish fed dietary linseed oil showed a higher proportion of DHA deposition on fatty acid profiles. High proportions of PUFA in the lipid profile of fish are generally related to high rates of lipogenesis, which consequently leads to lower lipid deposition (Glencross, 2009; Hatlen *et al.*, 2012).

The different vegetable lipids sources in the diet resulted in variation in the fatty acid profile of the fish, but all oils tested provided similar growth performance indices.

Of note, as all diets met the nutritional requirements of energy and essential fatty acids (Veras *et al.*, 2010; Faria *et al.*, 2019); therefore, treatments were already expected not to affect fish growth performance. No difference in the growth performance parameters was neither observed for surubim (*Pseudoplatystoma coruscans*) (Martino *et al*., 2002) nor jundiá (Losekann *et al*., 2008; Vargas *et al*., 2008) fed different vegetable lipid sources, both Neotropical freshwater carnivorous species. Absence of growth performance effects was also observed for yellowfin seabream (*Acanthopagrus latus*) (Abbasi *et al*., 2020), rainbow trout (Shafaeipour *et al*., 2008), tilapia (*Oreochromis niloticus*) (Matsushita *et al*., 2006), tambaqui (*Colossoma macropomum*) (Paulino *et al*., 2018) and *Cyprinus carpio* (Graeff & Tomazelli, 2007) fed different vegetable lipid sources. On the other hand, the use of cod liver oil rich in PUFA n3 caused a decrease in the growth performance of South American catfish (*Pseudoplatystoma fasciatum*) (Arslan *et al*., 2008) and African catfish (*Clarias gariepinus*) (Ng *et al*., 2003). This effect is probably related to the high ratios of n3/n6 in these diets since the LNA (18:3 n3) and LA (18:2 n6) fatty acids are substrates of the same enzyme, Δ6 desaturase, and this enzyme has more affinity for the n3 precursors which can lead to more significant formation of PUFA n3 in relation PUFA n6 (Zheng *et al*., 2009). The n3/n6 ratio outside the acceptable range may promote adverse effects on fish development.

The fatty acid profiles of fish whole-body generally reflect the profile of the diets provided (Turchini *et al*., 2009; Olsen, 2011; Gomes *et al*., 2016). This was also confirmed for striped catfish (*Pangasius hypophthalmus*) (Asdari *et al*., 2011), rainbow trout (Yildiz *et al*., 2018), lambari (*Astyanax altiparanae*) (Pontes *et al*., 2019); largemouth bass (*Micropterus salmoides*) (Chen *et al*., 2020); gilthead seabream (*Sparus aurata*) (Ofori-Mensah *et al*., 2020). However, the fatty acid profiles of *H. lacerdae* showed distinct changes between the retention of some PUFA and the experimental fish diets, especially in the case of DHA. All vegetable oil sources tested did not present DHA. However, the presence of this fatty acid in the fish carcass suggests that *H. lacerdae*, like other freshwater fish species, can synthesize PUFA via desaturation and elongation of the LA and LNA (Tapiero *et al*., 2002; Tocher, 2003). Therefore, although fish fatty acid profiles are directly related to the fish diet, the fatty acid metabolism by fish can have a measurable effect (Emery *et al*., 2013), and this biosynthesis is one of the most targeted pathways under investigation (Tocher, 2015; Castro *et al*., 2016a).

Hoplias lacerdae juveniles fed diets containing canola oil had lower saturated fatty acid deposition than fish fed other lipid sources. This result was similar to that found for Murray cod (*Maccullochella peelii peelii*) when fed with canola oil compared to fish fed with fish oil and linseed oil (Francis *et al*., 2006; 2007). Therefore, these results indicate that the deposition of fatty acids in the fish whole-body did not correlate well with the composition of fatty acids in the diet since diets containing linseed oil, whose content of SFA was lower, caused, in the same way as diets with soybean oil, more significant deposition of these fatty acids. According to Turchini *et al*. (2003a,b), for some species, the deposition of SFA does not reflect the composition of the diet well, as these may not be used efficiently as an energy source and is preferably deposited in the whole-body of fish.

The highest values of LA in the fish whole-body fed diets supplemented with soybean oil, were due to the high proportion of this fatty acid in this diet. Similar results were observed for turbot (*Psetta maxima*) (Regost *et al*., 2003) and lambari (Pontes *et al*., 2019). Since diets supplemented with soybean, canola, and olive oil showed a higher proportion of LA in relation to LNA, ARA would be expected to be present in these fish since LA is the precursor to the synthesis of ARA. However, the presence of this acid was not detected in fish from all treatments. A DHA>EPA>ARA deposition ratio is common for lipid deposition, especially in carnivorous fish fed on vegetable oil sources (Fountoulaki *et al.*, 2009; Yildiz *et al.*, 2018). The low deposition of ARA in the fish muscle is explained by the fact that this fatty acid is preferentially deposited in other tissues, such as the liver. This result was similar to that of Pontes *et al*. (2019), who observed the absence of ARA in lambari fed with vegetable oil supplemented diets.

The higher LNA values found in fish fed a diet supplemented with linseed oil were also due to the high proportion of this fatty acid in this diet. For this reason, these fish were the only ones that presented EPA in the carcass and those that presented the highest deposition of DHA, which can be explained by the high levels of n3 PUFA in this oil source. Previous study attested that lambari fed linseed oil showed higher whole-body amounts of EPA and DHA than that fed soybean oil (Pontes *et al*., 2019). The higher retention of DHA to EPA is probably related to the fact that EPA has a faster rate of beta-oxidation in muscle and liver tissues (Herzberg *et al.*, 1996; Madsen *et al.*, 1998).

In fish fed the diet supplemented with olive oil, the proportions between the fatty acids were also kept compared with the diet. However, there were high amounts of monounsaturated fatty acids (MUFA) and lower amounts of LNA and, consequently, the DHA compared with the other diets. This result was similar to that observed in European sea bass (*Dicentrarchus labrax* L.) fed diets containing 60% olive oil in substitution for fish oil and compared with diets whose substitution was made with 60% soybean oil (Mourente *et al*., 2005).

The absence of significant differences in growth performance and the high deposition of PUFA in the carcass indicates that the evaluated vegetable lipid sources are suitable for the nutrition of giant trahira. Thus, the ability to modulate the fatty acid profile through the diet opens the possibility of producing fish with different fatty acid profiles for human consumption. Therefore, due to the higher deposition of DHA and EPA, in this study, linseed oil was considered a good vegetable lipid source for giant trahira.

Authors' contributions

Conceptualization: A. L. Salaro, T. R. A. Felipe, J. A. S. Zuanon, W. M. Furuya, G. C. Veras and D. A. V. Campelo.
Data curation: T. R. A. Felipe, C. L. S. Carneiro, J. A. S. Zuanon, C. M. Sabarense, A. P. S. Carneiro, G. C. Veras and D. A. V. Campelo.
Formal analysis: T. R. A. Felipe, C. L. S. Carneiro, J. A. S. Zuanon, C. M. Sabarense, A. P. S. Carneiro, G. C. Veras and D. A. V. Campelo.
Funding acquisition: A. L. Salaro and J. A. S. Zuanon.
Investigation: T. R. A. Felipe, C. L. S. Carneiro, J. A. S. Zuanon, C. M. Sabarense, A. P. S. Carneiro and D. A. V. Campelo.
Methodology: T. R. A. Felipe, C. L. S. Carneiro, J. A. S. Zuanon, C. M. Sabarense, A. P. S. Carneiro and D. A. V. Campelo.
Project administration: A. L. Salaro and J. A. S. Zuanon
Resources: A. L. Salaro, J. A. S. Zuanon, C. M. Sabarense
Software: T. R. A. Felipe, C. L. S. Carneiro, J. A. S. Zuanon, C. M. Sabarense, A. P. S. Carneiro and D. A. V. Campelo.
Supervision: A. L. Salaro.
Validation: Not applicable.
Visualization: Not applicable.
Writing – original draft: A. L. Salaro, C. L. S. Carneiro, J. A. S. Zuanon, W. M. Furuya, G. C. Veras and D. A. V. Campelo.
Writing – review & editing: A. L. Salaro, C. L. S. Carneiro, J. A. S. Zuanon, W. M. Furuya, G. C. Veras and D. A. V. Campelo.

References

Abbasi A, Oujifard A, Torfi MM, Habibi H, Nafisi BM, 2020. Dietary simultaneous replacement of fish meal and fish oil with blends of plant proteins and vegetable oils in yellowfin seabream (*Acanthopagrus latus*) fry: Growth, digestive enzymes, antioxidant status and skin mucosal immunity. Aquac Nutr 26(4): 1131-1142. https://doi.org/10.1111/anu.13070

Alhazzaa R, Nichols PD, Carter CG, 2018. Sustainable alternatives to dietary fish oil in tropical fish aquaculture. Rev Aquacult 11(4): 1195-1218. https://doi.org/10.1111/raq.12287

AOAC, 2000. Official methods of analysis, 17th edn. Assoc Offic Anal Chem Int, Gaithersburg, MD, USA.

Arslan M, Rinchard J, Dabrowski K, Portella MC, 2008. Effects of different dietary lipid sources on the survival, growth, and fatty acid composition of south american catfish, *Pseudoplatystoma fasciatum*, surubim, juveniles. J World Aquac Soc 39: 51-61. https://doi.org/10.1111/j.1749-7345.2007.00133.x

Asdari R, Aliyu-Paiko R, Hashim R, Ramachandran S, 2011. Effects of different dietary lipid sources in the diet for *Pangasius hypophthalmus* (Sauvage, 1878) juvenile on growth performance, nutrient utilization, body indices and muscle and liver fatty acid composition. Aquac Nutr 17: 44-53. https://doi.org/10.1111/j.1365-2095.2009.00705.x

Balfry SK, Higgs DA, 2001. Influence of dietary lipid composition on the immune system and disease resistance of finfish. In: Nutrition and fish health; Lim C & Webster Cd (Eds), The Haworth Press Inc., NY, pp: 213-234.

Bell JG, Mcghee F, Campbell PJ, Sargent JR, 2003. Rapeseed oil as an alternative to marine fish oil in diets of post-smolt Atlantic salmon (*Salmo salar*): changes in flesh fatty acid composition and effectiveness of subsequent fish oil "wash out". Aquac 218: 515-528. https://doi.org/10.1016/S0044-8486(02)00462-3

Castro LFC, Tocher DR, Monroig O, 2016a. Long-chain polyunsaturated fatty acid biosynthesis in chordates: Insights into the evolution of Fads and Elovl gene repertoire. Prog Lipid Res 62: 25-40. https://doi.org/10.1016/j.plipres.2016.01.001

Castro LFC, Corraze G, Diógenes AF, Larroquet L, Panserat S, Oliva-Teles A, 2016b. Regulation of glucose and lipid metabolism by dietary carbohydrate levels and lipid sources in gilthead sea bream juveniles. Br J Nutr 116(1): 19-34. https://doi.org/10.1017/S000711451600163X

Chen Y, Sun Z, Liang Z, Xie Y, Su J, Luo Q, Wang A, 2020. Effects of dietary fish oil replacement by soybean oil and L-carnitine supplementation on growth performance, fatty acid composition, lipid metabolism and liver health of juvenile largemouth bass, *Micropterus salmoides*. Aquac 516: 734596. https://doi.org/10.1016/j.aquaculture.2019.734596

Cyrino JEP, Portz L, Martino YR, 2000. Retenção de proteína e energia em juvenis de "Black Bass" *Micropterus salmoides*. Sci Agric 57: 609-616. https://doi.org/10.1590/S0103-90162000000400003

Emery JA, Hermon K, Hamid NK, Donald JA, Turchini GM, 2013. Δ-6 desaturase substrate competition: dietary linoleic acid (18: 2n-6) has only trivial effects on α-linolenic acid (18:3n-3) bioconversion in the teleost rainbow trout. PLoS One 8(2): e57463. https://doi.org/10.1371/journal.pone.0057463

Faria MDR, Cavalcante-Neto A, Allaman IB, Gomes ADO, Moreira RG, Hallerman EM, Hilsdorf AWS, 2019. The potential of *Hoplias malabaricus* (Characiformes: Erythrinidae), a Neotropical carnivore, for aquaculture. Aquac Fish 4(3): 89-97. https://doi.org/10.1016/j.aaf.2019.01.002

Folch J, Lees M, Stanley GS, 1957. A simple method for the isolation and purification of total lipides from animal tissues. J Biol Chem 226(1): 497-509. https://doi.org/10.1016/S0021-9258(18)64849-5

Fountoulaki EVA, Hurtado RGK, Karacostas INI, Alexis MN, 2009. Fish oil substitution by vegetable oils in commercial diets for gilthead sea bream (*Sparus aurata* L.); effects on growth performance, flesh quality

and fillet fatty acid profile: Recovery of fatty acid profiles by a fish oil finishing diet under fluctuating water temperatures. Aquac 289(3-4): 317-326. https://doi.org/10.1016/j.aquaculture.2009.01.023

Francis DS, Turchini GM, Jones PL, DE Silva SS, 2006. Effects of dietary oil source on growth and fillet fatty acid composition of Murray cod, *Maccullochella peelii peelii*. Aquac 253: 547-556. https://doi.org/10.1016/j.aquaculture.2005.08.008

Francis DS, Turchini GM, Jones PL, De Silva SS, 2007. Growth performance, feed efficiency and fatty acid composition of juvenile Murray Cod, *Maccullochella peelii peelii*, fed graded levels of canola and linseed oil. Aquac Nutr 13: 335-350. https://doi.org/10.1111/j.1365-2095.2007.00480.x

Glencross BD, 2009. Exploring the nutritional demand for essential fatty acids by aquaculture species. Rev Aquac 1: 71-124. https://doi.org/10.1111/j.1753-5131.2009.01006.x

Gomes AD, Tolussi CE, Boëchat IG, Pompêo ML, Cortez MP, Honji RM, Moreira RG, 2016. Fatty acid composition of tropical fish depends on reservoir trophic status and fish feeding habit. Lipids 51(10): 1193-1206. https://doi.org/10.1007/s11745-016-4196-z

Graeff A, Tomazelli A, 2007. Fontes e níveis de óleo na alimentação da carpa comum (*Cyprinus capio*, L.) na fase de crescimento. Ciênc Agrotec 31: 1545-1541. https://doi.org/10.1590/S1413-70542007000500041

Hatlen B, Berge GM, Odom JM, Mundheim H, Ruyter B, 2012. Growth performance, feed utilisation and fatty acid deposition in Atlantic salmon, *Salmo salar* L., fed graded levels of high-lipid/high-EPA Yarrowia lipolytica biomass. Aquaculture 364: 39-47. https://doi.org/10.1016/j.aquaculture.2012.07.005

Herzberg GR, Skinner C, Levy R, 1996. Eicosapentaenoic acid is oxidized more rapidly than docosahexaenoic acid by muscle and liver. Nutr Res 16(4): 639-644. https://doi.org/10.1016/0271-5317(96)00041-3

IUPAC, 1987. Standard methods for the analysis of oils, fats and derivatives, 7th ed. Paquot C, Hautfenne A (Eds). Blackwell Sci Publ, Oxford, London, 151 pp.

Kasai RYD, Salaro AL, Zuanon JAS, Sabarense CM, Tavares MM, Campelo DAV, 2011. Feed training of giant trahira fingerlings fed diets containing different levels of vitamin C. Rev Bras Zootecn 40: 463-468. https://doi.org/10.1590/S1516-35982011000300001

Kostik V, Memeti S, Bauer B, 2013. Fatty acid composition of edible oils and fats. J Hyg Eng Des 4: 112-116.

Loro VL, Luz RK, 2020. Aspectos da biologia, reprodução e manejo de *Hoplias malabaricus* e *Hoplias lacerdae*. In: Espécies nativas para a piscicultura no Brasil, 3rd ed; Baldisserotto B (ed). Editora UFSM, Santa Maria, Brazil, pp: 229-244.

Losekann ME, Neto JR, Emanuelle T, Pedron FA, Lazzari R, Bergamin GT, *et al.,* 2008. Alimentação do jundiá com dietas contendo óleos de arroz, canola ou soja. Cienc Rural 38: 225-230. https://doi.org/10.1590/S0103-84782008000100036

Luz RK, Portella MC, 2005. Effects of feeding frequency on larval rearing of trairao (*Hoplias lacerdae*). Braz J Anim Sci 34(5): 1442-1448. https://doi.org/10.1590/S1516-35982005000500003

Luz RK, Salaro AL, Souto EF, Reis A, Sakabe R, 2001. Desenvolvimento de alevinos de trairão alimentados com dietas artificiais em tanques de cultivo. Braz J Anim Sci 30: 1159-1163. https://doi.org/10.1590/S1516-35982001000500004

Luz RK, Salaro AL, Souto EF, Okano WY, Lima RR, 2002. Training strategies trairao fingerlings (*Hoplias* cf. *lacerdae*). Braz J Anim Sci 31: 1881-1885. https://doi.org/10.1590/S1516-35982002000800002

Madsen L, Frøyland L, Dyrøy E, Helland K, Berge RK, 1998. Docosahexaenoic and eicosapentaenoic acids are differently metabolized in rat liver during mitochondria and peroxisome proliferation. J Lipid Res 39(3): 583-593. https://doi.org/10.1016/S0022-2275(20)33296-X

Martino RC, Cyrino JEP, Portz L, Trugo LC, 2002. Performance and fatty acid composition of surubim (*Pseudoplatystoma coruscans*) fed diets with animal and plant lipids. Aquac 209: 235-248. https://doi.org/10.1016/S0044-8486(01)00847-X

Matsushita M, Visentainer JV, Souza NE, Hayashi C, Santos Júnior OO, Silva ABM, Furuya WM, 2006. Centesimal composition and fatty acids profile of freshwater prawn. Braz J Anim Sci 34: 1577-1580.

Mourente G, Good JE, Bell JG, 2005. Partial substitution of fish oil with rapeseed, linseed and olive oils in diets for European sea bass (*Dicentrarchus labrax* L.): effects on flesh fatty acid composition, plasma prostaglandins E2 and F2, immune function and effectiveness of a fish oil finishing diet. Aquac Nutr 11: 25-40. https://doi.org/10.1111/j.1365-2095.2004.00320.x

Nanton DA, Vegusdal A, Rorã AMB, Ruyter B, Baeverfjord G, Torstensen B, 2007. Muscle lipid storage pattern, composition, and adipocyte distribution in different parts of Atlantic salmon (*Salmo salar*) fed fish oil and vegetable oil. Aquac 265: 230-243. https://doi.org/10.1016/j.aquaculture.2006.03.053

Nayak M, Saha A, Pradhan A, Samanta M, Giri SS, 2017. Dietary fish oil replacement by linseed oil: Effect on growth, nutrient utilization, tissue fatty acid composition and desaturase gene expression in silver barb (*Puntius gonionotus*) fingerlings. Comp Biochem Physiol B Biochem Mol Biol 205: 1-12. https://doi.org/10.1016/j.cbpb.2016.11.009

Ng WK, Lim PK, Boey PL, 2003. Dietary lipid palm oil sources affects growth, fatty acid composition and muscle α-tocopherol concentration of African catfish (*Clarias gariepinus*). Aquac 215: 229-243. https://doi.org/10.1016/S0044-8486(02)00067-4

Nogueira GCCB, Salaro AL, Luz RK, Zuanon JAS, Lamberttuci DM, Salerno RA, *et al.,* 2005. Desempenho

produtivo de juvenis de trairão (*Hoplias lacerdae*) alimentados com rações comerciais. Rev Ceres 52(302): 401-497.

Ofori-Mensah S, Yildiz M, Arslan M, Eldem V, 2020. Fish oil replacement with different vegetable oils in gilthead seabream, *Sparus aurata* diets: Effects on fatty acid metabolism based on whole-body fatty acid balance method and genes expression. Aquac 529: 735609. https://doi.org/10.1016/j.aquaculture.2020.735609

Oliva-Teles A, Enes P, Peres H, 2015. Replacing fishmeal and fish oil in industrial aquafeeds for carnivorous fish. In: Feed and feeding practices in Aquaculture; Davis DA (Ed), Woodhead Publ, Oxford, pp: 203-233. https://doi.org/10.1016/B978-0-08-100506-4.00008-8

Olsen Y, 2011. Resources for fish feed in future mariculture. Aquac Environ Interact 1: 187-200. https://doi.org/10.3354/aei00019

Oyakawa OT, Mattox GM, 2009. Revision of the Neotropical trahiras of the *Hoplias lacerdae* species-group (Ostariophysi: Characiformes: Erythrinidae) with descriptions of two new species. Neotrop Ichthyol 7(2): 117-140. https://doi.org/10.1590/S1679-62252009000200001

Paulino RR, Pereira RT, Fontes TV, Oliva-Teles A, Peres H, Carneiro DJ, Rosa PV, 2018. Optimal dietary linoleic acid to linolenic acid ratio improved fatty acid profile of the juvenile tambaqui (*Colossoma macropomum*). Aquac 488: 9-16. https://doi.org/10.1016/j.aquaculture.2018.01.014

Pontes MD, Campelo DAV, Ferraz RB, Zuanon JA, Furuya WM, Salaro AL, 2019. Soybean and linseed oil in replacement of fish oil in diets for female lambari *Astyanax altiparanae* Garutti & Britski, 2000. Lat Am J Aquat Res 47(2): 260-269. https://doi.org/10.3856/vol47-issue2-fulltext-6

Ramos ARP, Campelo DAV, Carneiro CLS, Zuanon JAS, Matta SLP, Furuya WM, Salaro AL, 2022. Optimal dietary L-glutamine level improves growth performance and intestinal histomorphometry of juvenile giant trahira (*Hoplias lacerdae*), a Neotropical carnivorous fish species. Aquac 547, 737469. https://doi.org/10.1016/j.aquaculture.2021.737469

Regost C, Arzel J, Robin J, Rosenlund G, Kaushik SJ, 2003. Total replacement of fish oil by soybean or linseed oil with a return to fish oil in turbot (*Psetta maxima*) 1. Growth performance, flesh fatty acid profile, and lipid metabolism. Aquac 217: 465-482. https://doi.org/10.1016/S0044-8486(02)00259-4

Rostagno HS, Albino LFT, Donzele JL, Gomes PC, Oliveira RF, Lopes DC, *et al.,* 2005. Tabelas brasileiras para suínos e aves: composição de alimentos e exigências nutricionais, 2nd ed, Viçosa: UFV, 186 pp.

Salaro AL, Luz RK, Nogueira GCCB, Reis A, Sakabe R, Lambertucci DM, 2003. Effect of two stocking rates on the trairão (*Hoplias* cf. *lacerdae*) fingerlings performance (*Hoplias* cf. *lacerdae*). Braz J Anim Sci 32(5): 1033-1036. https://doi.org/10.1590/S1516-35982003000500001

Salaro AL, Luz RK, Sakabe R, Kasai RYD, Lambertucci DM, 2008. Feeding levels for «trairão» juveniles (*Hoplias lacerdae*). Braz J Anim Sci 37: 967-970. https://doi.org/10.1590/S1516-35982008000600002

Salaro AL, Oliveira Junior JCD, Pontes MD, Oliveira KRBD, Neves Igada, Ferraz RB, Zuanon JAS, 2012. Replacement of moist ingredients in the feed training of carnivorous fish. Braz J Anim Sci 41(10): 2294-2298. https://doi.org/10.1590/S1516-35982012001000022

Sargent JR, Tocher DR, Bell JG, 2002. The lipids. In: Fish nutrition, 3rd ed; Halver JE (Ed), Acad Press, San Diego, USA, pp: 181-257. https://doi.org/10.1016/B978-012319652-1/50005-7

Shafaeipour A, Yavari V, Falahatkar B, Maremmazi JGH, Gorjipour E, 2008. Effects of canola meal on physiological and biochemical parameters in rainbow trout (*Oncorhynchus mykiss*). Aquac Nutr 14: 110-119. https://doi.org/10.1111/j.1365-2095.2007.00509.x

Tapiero H, Nguyen BAG, Couvreur P, Tew KD, 2002. Polyunsaturated fatty acids (PUFA) and eicosanoids in human health and pathologies. Biomed Pharmacother 56: 215-222. https://doi.org/10.1016/S0753-3322(02)00193-2

Tocher DR, 2003. Metabolism and functions of lipids and fatty acids in teleost fish. Rev Fish Sci 11(2): 107-184. https://doi.org/10.1080/713610925

Tocher DR, 2015. Omega-3 long-chain polyunsaturated fatty acids and aquaculture in perspective. Aquac 449: 94-107. https://doi.org/10.1016/j.aquaculture.2015.01.010

Torstensen BE, Bell JG, Rosenlund G, Henderson RJ, Graff IE, 2005. Tailoring of Atlantic salmon (*Salmo salar* L.) flesh lipid composition and sensory quality by replacing fish oil with a vegetable oil blend. J Agric Food Chem 53: 10166-10178. https://doi.org/10.1021/jf051308i

Trushenski JT, Rombenso AN, 2020. Trophic levels predict the nutritional essentiality of polyunsaturated fatty acids in fish-introduction to a special section and a brief synthesis. N Am J Aquac 82(3): 241-250. https://doi.org/10.1002/naaq.10137

Turchini GM, Gunasekera RM, De Silva SS, 2003a. Effect of crude oil extracts from trout offal as a replacement for fish oil in the diets of the Australian native fish Murray cod *Maccullochella peelii peelii*. Aquac Res 34(9): 697-708. https://doi.org/10.1046/j.1365-2109.2003.00870.x

Turchini GM, Mentasti T, Frøyland L, Orban E, Caprino F, Moretti VM, Valfré F, 2003b. Effects of alternative dietary lipid sources on performance, tissue chemical composition, mitochondrial fatty acid oxidation capabilities and sensory characteristics in brown trout (*Salmo trutta* L.). Aquac 225(1-4): 251-267. https://doi.org/10.1016/S0044-8486(03)00294-1

Turchini GM, Torstensen BE, Ng WK, 2009. Fish oil replacement in finfish nutrition. Rev Aquac 1: 10-57. https://doi.org/10.1111/j.1753-5131.2008.01001.x

Turchini GM, Francis DS, Senadheera SPSD, Thanuthong T, De Silva SS, 2011. Fish oil replacement with different vegetable oils in Murray cod: evidence of an «omega-3 sparing effect» by other dietary fatty acids. Aquac 315(3-4): 250-259. https://doi.org/10.1016/j.aquaculture.2011.02.016

Vargas RJ, Guimarães De Souza SM, Kessler AM, Baggio SR, 2008. Replacement of fish oil with vegetable oils in diets for jundiá (*Rhamdia quelen* Quoy and Gaimard 1824): effects on performance and whole-body fatty acid composition. Aquac Res 39(6): 657-665. https://doi.org/10.1111/j.1365-2109.2008.01946.x

Veras GC, Salaro AL, Zuanon JAS, Carneiro APS, Campelo DAV, Murgas LDS, 2010. Growth performance and body composition of giant trahira fingerlings fed diets with different protein and energy levels. Pesqu Agropec Bras 45: 1021-1027. https://doi.org/10.1590/S0100-204X2010000900012

Yildiz M, Eroldoğan TO, Ofori-Mensah S, Engin K, Baltaci MA, 2018. The effects of fish oil replacement by vegetable oils on growth performance and fatty acid profile of rainbow trout: Re-feeding with fish oil finishing diet improved the fatty acid composition. Aquac 488: 123-133. https://doi.org/10.1016/j.aquaculture.2017.12.030

Zambiazi RC, Przybylski R, Zambiazi MW, Mendonça CB, 2007. Fatty acid composition of vegetable oils and fats. Bol Cent Pesqu Proc Aliment 25(1): 11-120. https://doi.org/10.5380/cep.v25i1.8399

Zheng X, Leaver MJ, Tocher DR, 2009. Long-chain polyunsaturated fatty acid synthesis in fish: Comparative analysis of Atlantic salmon (*Salmo salar* L.) and Atlantic cod (*Gadus morhua* L.) Δ6 fatty acyl desaturase gene promoters. Comp Biochem Physiol B Biochem Mol Biol 154(3): 255-263. https://doi.org/10.1016/j.cbpb.2009.06.010