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Original Article

Effects of replacement of dietary fish oil with plant oil on growth performance and fatty acid composition of spinefoot rabbitfish, *Siganus rivulatus*

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Abstract

A 95-day feeding study was carried out to evaluate the impact of complete replacement of fish oil by plant oils in the growth performance, feed consumption fatty acid and body composition of juvenile rabbitfish, *Siganus rivulatus*. There were four treatments i.e., A (fish oil diet), (linseed oil diet), C (soybean meal oil diet) and D (sunflower oil diet). The experimental trial was conducted in twelve 1.5-m^3 fiber glass tanks (n=3). Spinefoot rabbitfish juveniles had an average initial weight of 0.948 g ± 0.124 g and they were stocked at 50 fish per tank. Fish fed diet A showed significantly better growth rate, final body weight, and total body weight than fish fed on the other diets. Moreover, the best FCR was observed for diet A followed by diet C and diets B and D had the worst FCR. Fish body composition for crude protein, dry matter, ashes and gross energy at the end of the trial had not differed between the treatments. The highest polyunsaturated fatty acids (PUFA) was found in fish fed diet A followed in decreasing order by diets D, B, and C. Fish oil is a better dietary lipid source for Spinefoot rabbitfish juveniles, *Siganus rivulatus*, than plant oils. Among plant oils, soybean oil was better than linseed oil and sunflower oil as the main dietary fat source.

Keywords: fish oil, plant oils, growth, feed efficiency, fatty acids, rabbit fish, *Siganus rivulatus*.

Resumo

Um estudo de alimentação de 95 dias foi realizado para avaliar o impacto da substituição completa de óleo de peixe por óleos vegetais no desempenho de crescimento, composição corporal e consumo de ração de juvenis de coelho, *Siganus rivulatus*. Houve quatro tratamentos, ou seja, A (dieta de óleo de peixe), (dieta de óleo de linhaça), C (dieta de óleo de farelo de soja) e D (dieta de óleo de girassol). O ensaio experimental foi conduzido em doze tanques de fibra de vidro de 1,5 m^3 (n=3). Os juvenis de peixe-coelho-de-espinho apresentaram peso inicial médio de 0,948 g ± 0,124 g e foram estocados com 50 peixes por tanque. Os peixes alimentados com a dieta A apresentaram taxa de crescimento, peso corporal final e peso corporal total significativamente melhores do que os peixes alimentados com as outras dietas. Além disso, a melhor CAA foi observada para a dieta A seguida da dieta C e as dietas B e D tiveram a pior CA. A composição corporal dos peixes para proteína bruta, matéria seca, cinzas e energia bruta ao final do experimento não diferiu entre os tratamentos. O maior teor de ácidos graxos poliinsaturados (PUFA) foi encontrado nos peixes alimentados com a dieta A seguido em ordem decrescente pelas dietas D, B e C. O óleo de peixe é uma melhor fonte de lipídios dietéticos para juvenis de peixe-coelho, *Siganus rivulatus*, do que os óleos vegetais. Entre os óleos vegetais, o óleo de soja foi melhor que o óleo de linhaça e o óleo de girassol como principal fonte de gordura da dieta.

Palavras-chave: óleo de peixe, óleos vegetais, crescimento, eficiência alimentar, ácidos graxos, peixe-coelho, *Siganus rivulatus*.

Introduction

Fish is the cheapest source of high-quality protein fatty acids and antioxidants that can protect our body against certain diseases (Khalid et al., 2021). Fish has been an important dietary source of protein and other nutrient throughout human history (Ahmad et al., 2021; Khan et al., 2024; Hassan et al., 2024). Aquaculture is one

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of the fastest emerging food-producing sectors globally and plays a crucial role in the culture of aquatic species for food and nutritional reliability (Hussain et al., 2021; Hassan et al., 2021a, b). In sustainable aquaculture practice is necessary to minimize costs and maximize growth is needed to replacement of fish and plant oil for enhancing growth, survival and production (Hassan et al., 2022). Rabbit fish is a largely demersal herbivore fish, which is belong to genus *Siganus* of family Siganidae. *Siganus rivulatus* is commonly known as Marbled spinefoot rabbitfish, which is commonly used for warm water marine aquaculture diversification. Siganids are found in both marine and brackish waters (Saoud et al., 2008). This species is native of Red sea and Western Indian Ocean, and are also useful for traditional and profitable exports in fisheries. This species is now being used in aquaculture in fish ponds or cages in several regions of the world (Duray, 1990; Woodland, 1990; Abdel-Aziz, 2017; Abdel-Aziz and Ragab, 2017). This might be because this species have a high tolerance rate against several environmental factors or during rough handling or in overcrowding (Hassan et al., 2023), therefore could be easily stocked in a very high density. Moreover, Rabbit fish is now considering as a best species in regions of the world, particularly, in eastern Mediterranean Sea as well as in Indo-Pacific regions. This species has great economic importance and are comparatively easy to rear; thus consider as suitable fish for farming (Saoud et al., 2007a; Abdel-Aziz et al., 2016).

The higher prices and uncertainty of fish oil (FO) availability has led to shifting of attention towards plant oils that have very low rate and higher production in volume than the fish oil (Bell et al., 2003; Mohammed et al., 2017; Nassef et al., 2019; Erondu and Akpoilih, 2020). Several studies revealed that plant oils can easily replace fish oil and it could be used in the fish diets without affecting their growth and survival (Ng et al., 2003; Bell et al., 2003; Wonnacott et al., 2004; Francis et al., 2006). However, the utilization of vegetable oils can produce variation in the composition of fatty acids in the body tissue of most marine fishes (Ganga et al., 2005; Peng et al., 2008; Cho, 2012).

According to the requirement for fatty acids in fish diet, the most marine fishes commonly have only omega-3 polyunsaturated fatty acids (PUFA), which was originating from marine phytoplankton. Though, lipids in many marine fish species contain comparatively high levels of omega-6 PUFA, because they feed on seaweeds, which also contain higher level of omega-6 PUFA. Generally, it is known that omega-3 PUFA are basic requirements for all kinds of Sea fauna subtropical species. In particular, docosahexaenoic acid (DHA) is an essential fatty acid, which is important for fish growth and survival. DHA is necessary for the development of red sea bream and juvenile striped jack as observed by Watanabe et al. (1989). Thus, this study aimed to observe the effects of the complete replacement of fish oil (FO) with plant oils as the chief source of lipids in fish diet on juvenile rabbitfish growth, feed consumption and body chemical composition.

2. Materials and Methods

2.1. Study area

In this study, *Siganus rivulatus* juveniles were collected from the Mediterranean Sea, Egypt. The whole experimental trial was carried out using the research facilities of NIOF, Egypt. The average initial weight (W_1) was 0.948 g ± 0.124, and the average the initial length of 3.97 cm ± 0.200, and the initial condition index (CI_1) was 1.51 gcm^{-3}. Juveniles were acclimatized to Lake Qaroun water condition (33 parts per thousand, ppt) and lab conditions for one week prior to size grading and the removal of large and small fish. Seed were equally stocked in 12 fiber glass tanks with stocking rate of 50 fish/tank. The dimensions of each tank were 3.9 m × 1.0 m × 0.6 m (L: W: H with water volume 1.5 m^3/tank). Fish fed twice daily at 8.00 a.m. and 4 p.m. at 5% of their biomass and water was exchanged at 20% on a daily basis. This trial continued for 95 days.

2.2. Diet preparation

The trial consisted of four treatments to evaluate three different plant oils (Table 1). The artificial diets A, B, C and D were formulated to have fish (FO), linseed (LO), soybean (SBO) and sunflower (SFO) oils as fat sources, respectively, with 36.44% crude protein for all. The fatty acid compositions of the diets are presented in Table 2. Each treatment had three replicates.

2.3. Experimental tanks

The culture system included a sand filter unit, a water pump, and two 10,000-L tanks to store water between the specified sources of water, Lake Qaroun and the trial tanks. The water pump also moved water from the source to the sand filter unit, and to the experimental groups from the storage tanks.

2.4. Aeration system of tanks

Aeration system included an air pump or blower, which was linked with a network system of plastic pipes that carried air to each tank. The tanks' taps were utilized to control the air diffusion, and air diffusers were employed to spread the air in all trial tanks.

2.5. Water quality

Physicochemical parameters included pH, salinity, temperature, DO and electrical conductivity (EC) were measured daily at 01:00 pm for each treatment. DO was measured by using oxygen meter (Model: HI9146), a centigrade thermometer used for temperature, refractometer (VITAL Sine SR-6, China) for salinity, Orion digital pH meter model 201 for pH, conductivity meter model (YSI.SCT-33) for calculating EC. Total ammonia, nitrite and nitrate concentrations were measured during each two weeks by using the chemical methods of APHA (1992).

2.6. Measurements of some of the internal organs, growth performance, and feed utilization efficiency

Morphological and growth parameters as weight gain (WG, g), average daily weight gain, (ADWG), protein

Table 1. Formulation of experimental diets and their proximate chemical compositions.

Ingredients (g/100 g)	Diet (A)	Diet (B)	Diet (C)	Diet (D)
Fish meal (72%CP)	22	22	22	22
Wheat bran fine	28	28	28	28
Soybean meal (37% CP)	43	43	43	43
Fish oil	4	-	-	-
Linseed oil	-	4	-	-
Soybean oil	-	-	4	-
Sunflower oil	-	-	-	4
Starch	1.7	1.7	1.7	1.7
Vit. & Min. & premix	0.3	0.3	0.3	0.3
Super yeast	1	1	1	1
Total	100	100	100	100
Proximate chemical analysis % on Dry matter basis				
Dry matter (DM)	93.06			
Ether extract (EE)	13.78			
Crude protein (CP)	36.44			
Moisture (M)	6.94			
Nitrogen free extract (NFE)	39.02			
Crude fiber (CF)	3.10			
Ash	7.66			
Gross energy (GE, Kcal/g)*	5.09			
Protein / Gross energy (P/GE)	7.16			

The chemical analysis was performed in accordance with AOAC (2010), and the NFE was computed by difference. *Calculated in accordance with the NRC (1993).

efficiency ratio (PER), Final condition index (CIf,g/cm3), hepatosomatic index (HSI) and viscerosomatic index (VSI), survival rate (SR, %), feed conversion ratio (FCR), relative growth rate (RGR,%), feed intake (FI), g/ fish protein productive value (PPV, %) energy efficiency ratio (EER, g/Kcal) energy productive value (EPV, %) lipid retention (LR, %), Were also calculated with the help of the Hassan et al. (2021a, b) (Equations 1-14).

$$\text{Specific Growth Rate}(\text{SGR}) = \frac{((\ln \text{W2} - \ln \text{W1}))}{(\text{Number of days})} \times 100 \quad (1)$$

$$\text{Feed intake g / fish(FI, g / fish} = \frac{\begin{pmatrix}\text{feed intake during}\\ \text{the trial period}\end{pmatrix}}{(\text{Number of fish at end})} \times 100 \quad (2)$$

$$\text{EPV, \%} = \frac{(\text{Retained Energy, Kcal})}{(\text{Energy intake, Kcal}))} \times 100 \text{ Lipid retention} \quad (3)$$

$$\text{ADG, g / day} = \frac{(\text{TG})}{(\text{T}))} \times 100 \text{ Lipid retention} \quad (4)$$

$$\text{FCR} = \frac{(\text{feed intake, g})}{(\text{TG})} \quad (5)$$

$$\text{WG}(\text{g}) = \text{W2} - \text{W1} \quad (6)$$

$$\text{PER} = \frac{(\text{TG g})}{(\text{Protein intake, g.})} \quad (7)$$

$$\text{LR \%} = \frac{(\text{Retained lipid, g})}{(\text{Lipid intake, g}))} \times 100 \quad (8)$$

$$\text{Final condition index}(\text{CIf, g / cm3}) = \frac{(\text{W2})}{(\text{L}^3\text{2})} \times 100 \quad (9)$$

$$\text{PPV, (\%)} = \frac{(\text{Retained protein, g})}{(\text{Protein intake, g})} \times 100 \quad (10)$$

$$\text{EER} = \frac{(\text{TG, g})}{(\text{Energy intake, Kcal})} \times 100 \quad (11)$$

$$\text{HSI(\%)} = \frac{(\text{Liver weight})}{(\text{Body weight})} \times 100 \quad (12)$$

$$\text{VSI}(\%) = \frac{(\text{Weight of viscera and associated fat tissue})}{(\text{Body weight})} \times 100 \quad (13)$$

$$\text{Survival rate}(\text{SR, \%}) = \frac{(\text{Number of fish at end})}{(\text{Number of fish at start})} \times 100 \quad (14)$$

2.7. Analysis of chemical composition of whole fish body and fish feeds

At the end of the trial, ten fish were randomly selected from each tank for that same purpose. The chemical analysis of whole-body fish samples and diets was calculated in accordance with AOAC (2010), and the diets' GE was assessed by using the factors 5.64, 9.44, and 4.11 Kcal/g for CP, EE, and carbohydrates, respectively, and 5.5 and 9.5 Kcal/g for protein and fats' fish samples, respectively (Viola et al., 1981; NRC, 1993).

2.8. Fatty acid analysis and Gas Chromatography (GC)

Lipid extraction was done in accordance to Egan et al. (1981), Jumat et al. (2006) and Siew et al. (1995). The composition of fatty acids in oils was assessed by using fatty acid methyl esters, which were then introduced into GC for analysis. Peak identification was accomplished through the use of retention times (Top et al., 2011).

2.8.1. Gas chromatography conditions

Model (HP), 6890GC (FID), injector temperature 220°C, detector temperature 240°C, injection volume 3l, Split ratio 50:1, column:DB-23 (50 percent Cyanopropyl

Table 2. Composition of fatty acids in the experimental diets (%).

Fatty acid		*Diet*			
		A (FO)	B (LO)	C (SBO)	D (SFO)
C14:0	Myristic	1.90	0.80	0.91	0.26
C16:0	Palmitic	15.70	8.58	12.58	7.20
C17:0	Margaric	ND	ND	ND	ND
C18:0	Stearic	3.70	4.35	4.50	4.10
C20:0	Arachidic	ND	1.07	1.23	0.89
C22:0	Behenic	ND	ND	ND	ND
∑SFA		21.30	14.80	19.22	12.45
C15:1	Pentadecanoic	ND	ND	0.50	ND
C16:1	Palmitoleic	5.60	1.50	1.60	1.30
C18:1 ω-9	Oleic	17.32	21.70	15.00	42.44
C20:1 ω-9	Eicosenoic	1.20	0.55	4.01	5.30
C22:1 ω-9	Erucic	ND	0.24	ND	ND
∑MUFA		24.12	23.65	21.11	50.04
C18:2 ω-6	Linoleic	4.30	38.63	27.20	20.33
C18:3 ω-3	Linolenic	ND	15.22	6.53	5.12
C20:2 ω-6	Eicosadienoic	3.18	0.31	ND	ND
C20:3 ω-3	Eicosatrienoic	1.52	0.57	0.54	1.75
C20:4 ω-6	Arachidonic	3.97	4.08	21.65	5.46
C20:5 ω-3	Eicosapentaenoic	10.79	ND	ND	2.10
C22:2	Docosadienoic	3.15	2.10	3.40	1.98
C22:6 ω-3	Docosahexaenoic	27.00	ND	ND	ND
∑PUFA		53.91	61.18	59.32	36.74
Unidentified		0.67	0. 64	0.35	1.77
∑ ω-3		39.31	15.79	7.07	8.97
∑ ω-6		11.45	43.02	48.85	25.79
∑ω-3/ ∑ω-6		3.43	0.37	0.14	0.35

methylpolysiloxane), 30, 0.32 mm ID, 0.25m film thickness. The carrier gas is nitrogen, and the gas flow rate is one milliliter per minute. Oven program: Initial temperature of 140 °C for 5 minutes, ramps 1, rate of oC/min 4, and final temperature of 240 °C.

2.9. Statistical analysis

The one-way ANOVA and Duncan Waller's least significant tests (LSD) were used to compare treatment means. The Statistical Software SPSS Version 16.0 was used to analyze the data. The significance level was calculated at $p<0.05$.

3. Results

3.1. Water quality parameters of experimental trials

Water physiochemical parameters were not significantly affected by dietary oil sources (Table 3). Temperature, pH, salinity, EC and DO ranged between 25.16 -25.28º C, 8.04 - 8.15, 33.701 - 33.80‰, 47.90 - 48.30 mS/cm and 6.10 - 7.03 mg/l, respectively. Nitrite, nitrate and total ammonia values ranged between 0.018 - 0.028 mg/l, 0.067 - 0.110 mg/l and 0.23 - 0.37 mg/l, respectively.

3.2. Composition of fatty acids in fish diets

Diet A contained the highest level (21.30% of fatty acids) of saturated fatty acid (SFA) followed by diet C (19.22%), diet B (14.8%) and diet D (12.45%; Table 2). Monounsaturated fatty acid (MUFA) was the lowest in diet C and the highest in diet D (50.04%), followed by diet A (24.12%) and diet B (23.65%). Diet D contained the lowest level of PUFA (36.74%) while diet B had the highest, followed by C and A. Diet B contained the highest level of linolenic acid (C18: 3ω3: 15.22%), followed by diet C (6.53%) and D (5.12%). Linolenic acid was not detected in diet A. Diet C had the highest arachidonic acid (C20:4ω6; 21.65%) followed by diet D (5.46%) and diet B (4.08%). Arachidonic acid was the

lowest in diet (A). Diet A had the highest eicosapentaenoic acid (EPA) C20:5ω3;10.79% and docosahexaenoic acid (DHA) 27% and both fatty acids did not appear in the other diets. Diet A had the highest ∑ω-3 (39.31%) followed by diets B, D and C. Diet C had the highest ∑ω-6 (48.85%) followed by diet B and D, while diet A recorded the lowest ∑ω-6 (11.45%). In general, diet A was better than the other diets in containing well balanced essential fatty acids.

3.3. Growth performance

The dietary oil sources significantly affected some growth parameters such as the final weight (W_2), TG, ADG and RGR (Table 4). Fish fed diet A surpassed in these parameters compared with other diets. Also, no significant differences in these parameters were observed between diet B and C. However, the averages of W_2, TG, ADG and RGR in fish fed diet C were higher than the fish fed diet B. Diet D, which contained sunflower oil as the main fat source, had the least $W_{2:}$ 3.70 g; TG: 2.75 g; ADG: 0.028 g and RGR: 290%.

3.4. Feed utilization efficiency

There were insignificant variances in FI (g/fish), FCR and EER (g/Kcal), but the highest FI (15.85g/fish) was recorded for diet D (Table 5). In contrast, the lowest FI (12.15 g/fish) was obtained with diet B. The best FCR was noted with the diet A followed by diet C. Diets B and D produced the worst FCR. The highest EER was obtained with diet A followed by diet B, while the lowest EER was achieved with diet C.

Table 3. Means (±SE) of physicochemical parameters.

Parameters	Treatments (Diet oil source)			
	Diet (A) Fish oil	Diet (B) Linseed oil	Diet (C) Soy bean oil	Diet (D) Sun flower oil
Temperature (ºC)	25.28±0.289	25.16±0.283	25.21±0.288	25.23±0.285
pH	8.15±0.229	8.04±0.230	8.07±0.220	8.04±0.234
Salinity ‰	33.80±0.284	33.70±0.263	33.78±0.245	33.79±0.221
EC mS/cm*	48.30±0.091	48.10±0.168	47.90±0.248	48.20±0.147
DO mg/l	6.71±0.490	6.10±0.510	7.03±0.575	6.54±0.765
Nitrite, mg/l	0.028±0.001	0.018±0.001	0.033±0.001	0.025±0.002
Nitrate, mg/l	0.067±0.001	0.088±0.002	0.067±0.002	0.110±0.003
Total ammonia, mg/l	0.24±0.003	0.23±0.001	0.30±0.002	0.37±0.001

*mS/cm, millisiemens/centimeter.

Table 4. The influence of diet oil source on rabbitfish juvenile growth indicators and survivability.

Attribute	Treatments (Diet oil source)				SED: *
	Diet (A) Fish oil	Diet (B) Linseed oil	Diet (C) Soybean oil	Diet (D) Sun flower oil	
Initial weight, (w1), g	0.948	0.948	0.948	0.948	-
Final length, (L2), cm	7.81^{a}	7.25^{ab}	7.19^{ab}	6.82^{b}	0.270
Final condition index (CIf), %	0.97^{c}	1.06^{b}	1.17^{a}	1.15^{a}	0.030
Final weight (W2), g	4.66^{a}	4.04^{ab}	4.40^{ab}	3.70^{b}	0.290
Total weight gain (TG), g	3.71^{a}	3.09^{ab}	3.45^{ab}	2.75^{b}	0.290
Average daily gain, (ADG), g/day	0.039^{a}	0.032^{ab}	0.036^{ab}	0.028^{b}	0.003
Relative growth rate (RGR),%	393.98^{a}	326.16^{ab}	364.55^{ab}	290.00^{b}	30.940
Specific growth rate (SGR/day, %)	1.67	1.52	1.61	1.26	0.160
Survival rate (SR, %)	88	94	87	95	10.740
Some of the internal organs parameters					
Hepatosomatic index (HSI, %)	2.39	2.31	1.50	2.37	0.630
Viscerosomatic index (VSI, %)	18.25	20.41	19.42	19.88	4.100

SED: Represented slandered devotion. *Statistical analysis.

3.5. Body composition and energy content

No significant variances were observed among the four groups at the end of the trail for CP, DM, ash and GE. However, the highest value of CP content was obtained with the diet B, followed by D, C and A. The peak value of ash was observed with diet A and the lowest value was obtained with diet D. The highest value of GE was obtained with diets D and B and the lowest value was obtained with diet C. EE in the whole-body juvenile rabbitfish was significantly differed between the four treatments, and the highest value was recorded for diets D and A, followed by diets B and C (Table 6).

3.6. Fatty acids profile of the whole-body juvenile rabbitfish (Siganus rivulatus) fed experimental diets formulated with different oil sources

The highest values for total saturated fatty acids (SFA) in rabbitfish whole-body were observed at the beginning of the experiment (43.82%), followed by fish fed with diets A (35.83%), C (31.74%), B (28.85%) and D (26.36%; Table 7). Palmitic acid was the main SFA in all fish samples and it was highest in fish fed diet A (24.21%). Also, the highest MUFA was recorded in fish fed on diet D (34.14%), followed by fish fed on diet B (33.05%), C (32.46%), initial fish (29.49%) and A (22.74%). The main MUFA was oleic acid. Palmitoleic acid was the second of MUFA in all investigated fish species, where oleic acid was found in high levels of fish fed diet B (21.65%), followed by fish fed on diets C, D, A. The highest PUFA was found in juvenile fish fed on diet A (40.21%), followed by diets D (37.55%), B (36.63%) and C (32.70%). Non-fed initial fish had the lowest PUFA (24.54%).

4. Discussion

Averages of these growth parameters in four treatments were found within the tolerable limits and the recommended ranges for juvenile rabbitfish (*Siganus rivulatus*) as reported by Saoud et al. (2007b). Fish growth was not significantly different among groups in SGR and SR. However, SGR for diet A was highest as compared to other groups. In contrast, the highest SR was observed to diets D and B compared with diets A and C. Fish fed with the diet A showed the greatest growth performance. This may be associated with the fact that the digestion and absorption of FOs are high. The addition of fish oils in the diet is reflected in the composition of the fats in different animals. Metabolizable energy and feed efficiency of fish oils are high (Mohammed et al., 2017). As fish oil (FO) is highly digestible, it produces a better growth rate and less amount of food wastage (FAO, 1986).

FO has been reported to provide the major benefits to animal health, i.e., it can improve immunity against

Table 5. The impact of diet oil source on juvenile rabbitfish feed utilization efficiency.

Attributes	Treatments (diet oil source)				SED*
	Diet (A) Fish oil	Diet (B) Linseed oil	Diet (C) Soy bean oil	Diet (D) Sun flower oil	
FI, g/ fish	13.33	12.15	13.41	15.85	1.710
FCR	3.58	3.92	3.85	3.93	0.181
PER	0.76^{a}	0.69^{b}	0.70^{b}	0.69^{b}	0.008
PPV %	33.90^{b}	35.40^{a}	33.05^{d}	33.45^{c}	0.009
EER, g/Kcal	0.054	0.050	0.045	0.049	0.008
EPV, %	31.44^{a}	30.55^{c}	27.54^{d}	30.78^{b}	0.030
LR, %	70.40^{a}	64.55^{c}	56.66^{d}	68.73^{b}	0.280

SED: Represented slandered devotion. *Statistical analysis.

Table 6. Whole-body biochemical composition and energy content (on DM basis) of juvenile's rabbitfish.

Items	Start	Treatments (Diet oil source)				SED*
		Diet (A) Fish oil	Diet (B) Linseed oil	Diet (C) Soybean oil	Diet (D) Sun flower oil	
Moisture (M, %)	81.48	71.25	70.91	72.07	71.00	0.707
Dry matter (DM, %)	18.52	28.74	29.09	27.93	29.00	0.707
Crude protein (CP, %)	62.02	47.95	53.34	50.07	51.63	5.460
Ether extract (EE, %)	11.78	30.15^{a}	29.52^{ab}	26.33^{b}	30.80^{a}	1.220
Ash, %	24.03	16.66	15.83	16.32	13.70	2.070
Gross energy (GE, Kcal/g)	4.53	5.50	5.74	5.25	5.76	0.280

*Statistical analysis. SED: Represented slandered devotion.

Table 7. Fatty acid profile (% of total fatty acid) of the complete body of rabbitfish (fed experimental diets with varied oil sources.

Fatty acids	(Untreated-fish) (Start fish)	*Fish fed on diet*			
		(A) Fish oil	(B) Linseed oil	(C) Soy bean oil	(D) Sun flower oil
C14:0 (Miristic acid)	5.45	2.94	0.47	1.35	0.83
C15:0 (Pentadecanoic acid)	4.12	1.04	0.95	ND	ND
C16:0 (Palmitic acid)	23.83	24.21	15.91	10.97	14.23
C17:0 (Heptadecanoic acid)	ND	0.45	ND	ND	0.44
C18:0 (Stearic acid)	3.25	1.34	6.15	17.20	6.80
C20:0 (Arachidic acid)	3.02	4.82	5.07	1.34	3.64
C22:0 (Behenic acid)	4.15	1.03	0.30	0.88	0.42
∑SFA	43.82	35.83	28.85	31.74	26.36
C14:1 (Myristoleic acid)	ND	ND	ND	0.87	ND
C16:1 (Palmitoleic acid)	8.34	5.31	8.29	9.05	10.85
C17:1 (Heptadecanoic acid)	1.17	ND	ND	ND	ND
C18:1c ω-9 (Oleic acid)	14.22	16.11	21.65	19.68	18.30
C20:1 ω-9 (Eicosenoic acid)	2.56	0.98	2.84	1.22	3.32
C22:1 ω-9 (Erucic acid)	3.20	0.34	0.27	0.92	1.67
∑MUFA	29.49	22.74	33.05	32.46	34.14
C18:2c ω-6 Linoleic acid	1.42	2.52	2.44	1.91	2.13
C18:3αω-3 (Linolenic acid)	ND	0.13	ND	ND	0.65
C20:2 ω-6 Eicosadienoic acid	1.67	2.29	2.41	2.04	2.55
C20:3 ω-3 Eicosatrienoic acid	1.89	0.82	ND	0.30	ND
C20:4 ω-6 Arachidonic acid	3.15	4.16	4.00	3.56	4.92
C20:5 ω-3 Eicosapentaenoic acid	5.60	6.15	6.24	6.00	7.13
C22:6 ω-3 Decosahexaenoic acid	9.81	24.14	21.54	18.90	20.17
∑PUFA	24.54	40.21	36.63	32.70	37.55
Unidentified	2.15	1.22	1.47	3.10	1.95
∑ω-3	17.30	31.24	27.68	25.20	27.95
∑ω-6	7.24	8.97	8.85	7.50	9.60
∑ω-3/ ∑ω-6	2.39	3.48	3.12	3.36	2.91

ND = not detected. SFA = total saturated fatty acids. MUFA = total monounsaturated fatty acids. PUFA = total polyunsaturated fatty acids -3 denotes the sum of omega three and -6 denotes the amount of omega six.

certain diseases, elicit higher survival rate and growth, and could also reduce the incidences of deformities (Schipp, 2008). FOs was used because of their growth-promoting effects, their vitamin A and D content. The reason for the growth-promoting activity of fish oil is that most fish require ω-3 fatty acids. The longer chain ω-3 fatty acids for example C20:5 and C22:6 are more beneficial than the shorter chain ω-3, C18:3 which some vegetable oils can provide. Diet A was the richest in ω-3 fatty acids (∑ω3: 39.31%), with almost exclusively the fatty acid C20:5ω3 (10.79% of fatty acids; Table 2). That agrees with Pike (1990) and El-Sayed et al. (2005) who also observed that broodstock of Nile tilapia maintained in brackish water needed n-3 HUFA for optimal spawning performance. The reproductive performance of fish reared in freshwater was unaffected by dietary lipid supply. Furthermore, diet A had the highest level of eicosadienoic acid (C20:2 n-6; 3.18%; Table 2). That agrees with Wilson et al. (1987) who also reported that Channel catfish can grow better with diets containing cod liver oil than vegetable oils. Those authors suggested that ω-3 highly unsaturated fatty acid in cod liver oil may be responsible for the enhanced fish growth. Total fish oil (FO) replacement with plant oils diets for sea bass (Izquierdo et al., 2003) and gilthead seabream (Montero et al., 2008) decreased fish growth. Santiago and Reyes (1993) had also observed the maximum weight gain in *O. niloticus* broodstock when fish were fed with cod liver oil. Likewise, Peng et al. (2008) had determined that the total replacement of FO by soybean oil (SBO) can significantly decrease the weight gain of black sea bream.

Salmonid species fed on an SBO diet grew at a pace comparable to those fed on a FO diet (Ruyter et al., 2006). On the other hand, *Heterobranchus longifilis* fed dietary SBO gained the least weight of any of the diet groups (Babalola and Apata, 2012). Despite the diet D had the highest MUFA levels, it recorded the lowest growth rate. This may be due to poor essential fatty acid balance in diet D, which agrees with Huang et al. (2014). Muralisankar et al. (2014), on the other hand, found that SFO-incorporated feed improved growth and survival in freshwater shrimp *Macrobrachium rosenbergii* PL and it can enhance freshwater prawn culture. Other trials with Atlantic salmon have demonstrated that replacing FO with SFO had no significant impact on profitability (Bell et al., 1996). Survival did not differ substantially among groups and varied from 87-95%, which is similar to the observed by Arslan et al. (2008), and El-Tawil et al. (2014). Our recommendations, on the other hand, contradict the results to the Atlantic salmon (Bell et al., 2003), red sea bream (Glencross et al., 2003), Atlantic cod (Bell et al., 2006), Murray cod (Francis et al., 2006) and seabream (Glencross et al., 2003), which showed that the total replacement of dietary fish oil by vegetable oils had revealed insignificant effect on growth rates. Likewise, FO substituted by SFO, palm oil, LO, rapeseed oil, peanut and coconut oils when incorporated in feed of *Diplodus puntazzo* could attain a significant enhancement in both fish survival and growth (Turchini et al., 2011).

Fish fed diet C had the lowest his (1.50%; P>0.05). The highest VSI (20.41%) was obtained with diet B, which agrees with Regost et al. (2003), Xu et al. (2011), Babalola and Apata (2012). However, Kowalska et al. (2010) have observed enhanced HSI in black carp (*Mylopharyngodon piceus*) fed rapeseed oil; and enhanced VSI in pikeperch (*Sander lucioperca*) fed peanut oil diets.

Our findings agree with Aminikhoei et al. (2014) who observed no substantial variation on feed efficiency, PER, daily FI and daily protein intake for Black sea bass fed four isonitrogenous and isolipidic diets with FO or SBO or linseed oil (LO) or with a mixture containing the SBO and LO. In a study by Tidwell et al. (2007), who studied the impact of various dietary lipids on the growth of Largemouth Bass, there were no significant differences for FCR and PPD. Moreover, Masiha et al. (2013) had reported the suitability of FO replacement by flaxseed and canola oils as a source of supplemental dietary lipid for the rainbow trout. These results conflict with Thiaw (2013) who found a significant effect of different types of oils on Nile tilapia's FCR. Similarly, Babalola and Apata (2012) reported *Heterobranchus longifilis* fingerlings' FCR was significantly affected by the dietary lipid sources.

Table 5 shows that there were significant differences in PER, PPV, EPV and LR. Diet A had the highest PER (0.76) and there were insignificant variances in PER among the other diets. Diet B had the highest PPV (35.40%) followed by diet B (33.90%). The lowest PPV was 33.05% and recorded for diet C. Diet A had the greatest EPV and LR followed by diets D, B and C, respectively. These results are supported by El-Tawil et al. (2014) who also reported that the best values of FCR were found in fish fed fish-oil diets (FO) and a mixture of 50% linseed oil and 25% corn oil plus 25% soybean oil diets. Besides, the best PER, PPV values were attained by fish fed on FO compared with a single plant-oil diets (LO, SBO and corn oil - CO). In addition, feed efficiency and PER values for Black sea bream were the highest with FO compared to SBO, LO and SBO+LO (Aminikhoei et al., 2014). On the contrary, Keremah and Terimokumo (2014) have found that both FCR and PER values for *Heterobranchus longifilis* fingerlings were lower by using cod liver oil diet than those fed on soybean oil diet.

In general, diet A was superior to the other treatments. Metabolizable energy and feed efficiency of FO is higher than for plant oils, as previously reported by El-Tawil et al. (2014), Mohammed et al. (2017), and Erondu and Akpoilih (2020). Those authors related that the highest feed utilization for Nile tilapia was obtained with fish oil followed by a mixture of plant oil (50% LO, 25% CO + 25% SBO). Thus, it has been concluded in the present study that the total replacement of dietary FO by plant oils has negative effects on both growth and feed consumption of juvenile rabbitfish. Fish fed on SBO had better growth rate and feed utilization than those fed on LO and sunflower oil. Therefore, the partial replacement of dietary FO by SBO or LO may improve the growth and the feeding utilization of juvenile rabbitfish. Moreover, it may reduce fish feed costs. That agrees with Xu et al. (2011) who also found that SBO was a more appropriate lipid source for *S. canaliculatus*, being able to replace up to 67% or 45% of FO with no negative impacts on the growth or nutritional value of fish, respectively. Izquierdo et al. (2005) stated that the use of vegetable oils up to 60% in place of FO in gilthead seabream diets has not affected fish growth and feed consumption even after a prolonged feeding time. Mourente et al. (2005) have observed that rapeseed linseed and olive oils could replace 60% of FO in the diet of Seabass, without decreasing growth rates. Moreover, Kamarudin et al. (2012) has reported that the partial replacement of FO by vegetable oil in *Tor tambroides* diet showed no adverse effect on fish growth and feed utilization.

El-Tawil et al. (2014) reported no significant differences between treatments for Nile tilapia whole body CP and moisture when fish fed on different oils sources. Likewise, dietary lipid sources did not affect moisture and ash contents of Black Sea bream muscles (Aminikhoei et al., 2014). In contrast, the dietary lipid sources significantly affected fish body moisture and crude protein contents of juvenile Amur sturgeon *Acipenser schrenckii* (Huang et al., 2014). In the present work lipid and ash contents were significantly elevated (Table 6). The same was observed by Muralisankar et al. (2014) who reported that the lipid and ash contents of *Macrobrachium rosenbergii* increased when fish fed on a diet with cod liver and sunflower oil. On the other hand, Aminikhoei et al. (2014) reported the dietary lipid source did not affect the crude lipid content of Black Sea bream muscles. The ω-3/ω-6 ratio is a reliable indicator to compare the relative nutritive value of different dietary oils. The highest ω-3/ω-6 ratio was found in samples of fish that fed on the experimental diets compared with original juvenile (start fish). Furthermore, an increase in the dietary ω-3/ω-6 fatty acid ratio for humans is required to prevent cardiovascular diseases by lowering plasma lipids. Juvenile rabbitfish fed on diet containing FO (diet

A) had the highest PUFA and nutritive value, followed by with SFO (diet D), LO (diet B) and SBO (diet C). Fish fed on diet A had better growth performance than fish fed on the other diets.

5. Conclusion

Fish oil is a better dietary lipid source for Spinefoot rabbitfish juveniles, *Siganus rivulatus*, than plant oils. Among plant oils, soybean oil was better than linseed oil and sunflower oil as the main dietary fat source. Furthermore, research in these areas would validate the significance of using different varieties of alternative oil resources ingredients with respect to enzyme activity and gene expression in fish.

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