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Evaluation of Skate Meal as a Replacement of Fishmeal in Diets for Nile Tilapia Fry (*Oreochromis niloticus*)

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Key words: fishmeal replacement, by-catch, skate fish, growth, digestibility

Abstract

A 12-week feeding experiment was conducted to evaluate the use of skate meal derived from fishery by-catches as a partial or complete replacement of fishmeal in diets for tilapia fry (*Oreochromis niloticus*). Five isonitrogenous (33%) and isoenergetic (15.3 kJ g-1) diets were formulated to replace 0 (control), 25%, 50%, 75%, or 100% of fishmeal by skate meal. Fish were stocked in triplicate groups of 20 fish in 120-l aquaria and fed three times daily to apparent satiation. Final body weight, weight gain, and specific growth rate in fish fed the diet containing skate meal at a replacement level of 25% were best and statistically similar to those in fish fed the control. Feed intake, feed conversion ratio, and protein efficiency ratio in fish fed the diets containing up to 50% replacement were similar to those fed the control. There were insignificant differences in the crude protein and ash contents of the final fish whole body, however, moisture and lipid content were significantly affected by dietary treatment. The highest apparent digestibility coefficients for protein, lipid, energy, and ash were obtained in fish fed the 25% replacement diet. Together, our results indicate that up to 25% of fishmeal can be replaced by skate meal in practical diets for tilapia fry without causing a significant reduction in growth performance, feed efficiency, body composition, or digestibility.

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Introduction

Feed comprises the largest production cost for aquaculture industries, representing up to 70% of the total costs. Fishmeal is a major ingredient in prepared diets for most fish. Due to the rapid growth of aquaculture industries, fishmeal is in short supply and rather costly (Hardy and Barrows, 2002). Thus, research into alternatives to fishmeal is an international priority (Goddard et al., 2008).

Fishery by-catches, discards, and by-products are potential protein sources for aquafeeds (Li et al., 2004). Further, by-catches, especially discarded by-catches, are a serious problem in the world's oceans (Herrington et al., 2005). Most commercial fishing gear is neither size nor species selective, and catch many non-targeted organisms that can damage or kill fish communities. Worldwide landings from capture fisheries equal approximately 89 million tons per year, of which an average 7.3 million tons of usually dead or dying fish are estimated to be discarded; 200,000 tons of these are cartilaginous fishes (FAO, 2009). The global weighted by-catch rate is 8% and trawl fisheries for pelagic and demersal fishes account for over 36% of this total (Zengin and Akyol, 2009). In Turkey, capture fisheries landed 486,000 tons in 2010, with an estimated average 20,000 tons of fish discarded annually by marine fisheries (TFS, 2011).

Discarded fishery by-catches represent lost economic opportunities for using such items to produce fishmeals, fish oils, fish pastes, etc. (Whiteman and Gatlin, 2005). If converted to fishmeal, fishery by-catches may provide a suitable alternative to commercial fishmeal that is largely derived from pelagic or demersal cartilaginous and bony fishes. In general, diets are best prepared from locally-available ingredients to simplify formulation and lower production costs. There may also be environmental benefits in utilizing fishery discards that are currently dumped at sea or in land-fills.

Fishmeals manufactured from fishery by-catches have been evaluated in diets for Nile tilapia *Oreochromis niloticus* (Goddard et al., 2008), coho salmon *Oncorhynchus kisutch* (Rathbone et al., 2001), rainbow trout *O. mykiss* (Hardy et al., 2005), and red drum *Scianops ocellatus* (Li et al., 2004; Whiteman and Gatlin, 2005). The present study evaluates the nutritional quality of cartilaginous skate meal from fishery by-catches as a partial or total replacement of fishmeal in practical diets for Nile tilapia fry.

Materials and Methods

Experimental diets. Fishery by-catches of skate fish (*Raja clavata, R. mirelatus, Dasyatis pestinaca, Grymmna altavela*) were caught by trawl in Antalya Bay in July 2009 and transported frozen to the laboratory of the Faculty of Fisheries of Akdeniz University, Antalya, Turkey. Whole skate fish were used to produce skate meal. All species were minced, boiled for 5 min, sun-dried for 8 h, oven-dried for 5 h at 70°C, ground in a hammer mill, and stored deep-frozen in plastic bags until use.

Five isonitrogenous (33% crude protein), isolipidic (8% crude lipid), and isoenergetic (15.3 kJ/g digestible energy) diets were formulated from fish, skate, and soybean meals (Table 1) in which 0 (control), 25%, 50%, 75%, or 100% of the fishmeal was substituted by skate meal (Table 2). The fishmeal was produced from Peruvian anchovies (*Engraulidae spp.*). Chromic oxide (0.5%) was added as an inert marker to assay digestibility. The dry ingredients were finely ground in a hammer mill (Tetra Technological Systems, Ankara, Turkey), passed through a 0.5 mm mesh sieve, and blended in a food mixer. The oils were added, then water was added at approximately 40% of the total weight of the ingredients. The resulting mixture was pressure-pelleted using a meat grinder with a 2-mm die. The pellets were dried in an oven at 50°C for 24 h, crumbled with a mortar and pestle, sieved through a 1-mm mesh, and stored deep-frozen in air-tight plastic bags until use.

Fish and culture system. The experiment was carried out at the Laboratory of Ortaca Vocational School of the University of Muğla, Turkey, from November 3, 2009, to January 25, 2010. Tilapia fry were obtained from the same laboratory. Fry were acclimated to laboratory conditions for 2 weeks in a 250-l glass aquarium and fed a control diet three times daily prior to the experiment. The experiment was conducted in fifteen 120-l glass

Table 1. Proximate, amino acid, and fatty acid compositions of fish, skate, and soybean meals used as protein sources in feeds for Nile tilapia fry.

	Fish	*Skate*	*Soy-bean*
Proximate composition (% wet wt)			
Dry matter	92.05	92.99	89.61
Crude protein	68.60	75.04	42.04
Crude lipid	10.08	7.26	2.57
Crude ash	12.58	10.01	7.03
Crude fiber	0.40	0.40	3.90
Nitrogen-free extract	0.37	0.29	34.05
Amino acid (g/100 g dry diet; n = 2)			
Alanine	33.7	40.2	20.7
Aspartic acid	86.7	79.2	21.2
Glutamic acid	57.3	80.7	69.6
Glycine	38.6	39.1	23.1
Hidoksil-L-prolin	35.0	53.3	9.2
Histidine	25.0	27.8	17.5
Isoleucine	36.8	49.8	22.2
Leucine	60.8	68.3	38.8
Lysine	76.4	63.8	41.8
Methionine	25.3	19.3	9.3
Phenylalanine	36.8	43.4	21.4
Proline	35.3	40.7	33.1
Serine	22.5	28.7	26.8
Threonine	29.8	39.4	25.6
Tyrosine	26.3	42.0	22.5
Valine	44.8	50.7	27.5
Fatty acid (%total fatty acids; n = 2)			
C14:0	5.5	2.9	-
C15:0	0.5	1.7	-
C16:0	22.0	24.5	12.4
C16:1	4.9	7.2	-
C17:0	1.3	2.2	-
C18:0	4.0	7.8	4.4
C18:1 n-9	10.9	12.7	18.8
C18:2 n-6c	1.4	1.2	54.3
C18:3 n-3	0.6	-	7.9
C20:1 n-9	2.5	0.8	-
C20:4 n-6	1.0	4.4	-
C20:5 n-3	12.4	4.1	-
C22:6 n-3	19.5	14.8	-
Total n-3	32.6	19.0	7.9
Total n-6	2.4	5.6	54.3

aquaria filled with 90 l dechlorinated tap water. Fry (avg 0.78 g) were stocked at 20 fish per aquarium with three replicates of each treatment. The aquaria were continuously aerated by air stones through a central air compressor. Up to 60% of the aquarium water was exchanged daily to maintain water quality. Water temperature was maintained constant at 26±1°C using electric heaters in each aquarium and the photoperiod was maintained at 14L:10D by fluorescent lighting throughout the experiment. Dissolved oxygen was 5.34±0.05 mg/l, pH 8.12±0.10, nitrite 0.11 mg/l, and nitrate 8.98 mg/l. Throughout the experiment, water quality parameters were within acceptable ranges for growth of tilapia fry (Stickney, 1979). Fish were hand-fed to apparent satiation three times per day (09:00, 13:00, 17:00) for 12 weeks by slowly introducing feed until feeding ceased.

Sampling. At the beginning and end of the experiment, all fry in each aquarium were moderately anesthetized with an ethanol solution of clove oil (0.2 g/l; Talya Herbal Inc., Antalya, Turkey) and weighed. A sample of 40 fish at the beginning of the feeding experiment and 10 fish from each aquarium at the end were sampled and stored deep-frozen in air-tight plastic jars until proximate composition, amino acid, and fatty acid analysis.

Proximate composition. Feed ingredients, feeds, feces, and fish were analyzed for dry matter, crude protein, crude fiber, and ash using standard methods (AOAC, 1995) as follows: dry matter after drying at 105°C for 24 h in an oven; crude protein (N × 6.25) by the Kjeldahl method (Gerhardt Analytical Systems, Königswinter, Germany) after acid digestion; crude lipid after extraction with ether extraction by the Soxhlet method (Behr Soxtec System KV5M, Düsseldorf, Germany); ash by incineration at 550°C for 12 h in a muffle furnace; fiber by drying and ashing after extraction with 0.5 M H_2SO_4 and 0.5 M NaOH; and nitrogen-free extract by subtracting the crude protein, crude lipid, ash, crude fiber, and moisture from 100.

Amino acids. Amino acids were analyzed following acid hydrolysis using a Phenomenex EZ fast GC-FID hydrolyzed amino acid analysis kit (Varian GC, CP-3800 GC, Varian Inc., CA, USA).

Fatty acids. Total lipids of the main protein ingredients, experimental diets, and fish meat from 10 of the stock fish at the outset of the experiment and 10 fish per aquarium at the end of the experiment were extracted by the Soxhlet method using *n*-hexane, then saponified and methylated for fatty acid quantification using the modified method of IUPAC (1979) for gas chromatographic analysis. Fatty acid was extracted with *n*-heptane and converted to methyl esters by crystal anhydride Na_2SO_4 before injecting into the gas chromatograph for analysis. Fatty acid methyl esters were identified with a Perkin Elmer Auto System XLGC gas chromatograph (Perkin Elmer Life and Analytical Sciences, Shelton, CT, USA) equipped with a hydrogen flame ionization detector (FID)

Table 2. Ingredients and proximate compositions of diets for Nile tilapia fry in which different levels of fishmeal were replaced by skate meal.

		Diet (% replacement of fishmeal)				
		0 (control)	*25*	*50*	*75*	*100*
Ingredient (%)						
Fishmeal		37.20	27.90	18.60	9.30	-
Maize starch		28.90	28.90	28.90	28.90	28.90
Soybean meal		21.50	21.50	21.50	21.50	21.50
Skate meal		-	8.54	17.10	25.60	34.14
Maize oil		2.40	2.80	3.20	3.60	4.00
Mineral mix[1]		3.00	3.00	3.00	3.00	3.00
Vitamin mix[2]		2.00	2.00	2.00	2.00	2.00
Fish oil		2.00	2.00	2.00	2.00	2.00
Cellulose		1.40	1.76	2.10	2.50	2.86
Carboxy-methylcallulose		1.00	1.00	1.00	1.00	1.00
Chromic oxide		0.50	0.50	0.50	0.50	0.50
Salt (NaCl)		0.10	0.10	0.10	0.10	0.10
Proximate composition (%, wet wt; means±SEM; n = 3)						
Dry matter		92.71±0.0	92.69±0.0	92.19±0.0	92.80±0.0	92.43±0.0
Crude protein		33.41±0.1	33.27±0.0	33.52±0.0	33.54±0.0	33.75±0.0
Crude lipid		8.18±0.01	8.22±0.1	8.17±0.0	7.81±0.0	8.03±0.0
Crude ash		10.46±0.0	10.61±0.0	10.63±0.0	10.39±0.0	10.22±0.0
Crude fiber		3.41±0.0	3.77±0.1	4.11±0.0	4.51±0.1	4.86±0.2
Nitrogen-free extract		33.37±0.2	33.25±0.1	32.06±0.2	33.86±0.0	32.85±0.0
Digestible energy (kJ/g)[3]		15.3	15.3	15.4	15.4	15.4
Amino acids	*required*	*(g/100 g, dry diet; n = 2)[4]*				
Alanine		18.6	20.9	17.6	16.9	17.6
Glycine		19.5	21.3	20.9	20.3	21.1
Valine	7.8	22.5	20.4	18.7	19.4	19.6
Leucine	9.5	25.7	28.7	28.3	28.4	26.9
Isoleucine	8.7	12.8	18.8	16.5	18.1	15.9
Threonine	10.5	10.5	19.9	18.1	15.9	16.0
Serine		13.8	14.6	15.7	13.0	13.8
Proline		12.1	18.5	16.6	16.2	16.7
Aspartic acid		39.1	33.4	38.2	36.2	37.6
Methionine	7.5	8.1	6.5	6.2	6.3	4.6
Hidoksil-L-prolin		21.9	19.5	26.2	23.1	23.8
Glutamic acid		23.6	31.5	31.5	31.2	34.4
Phenylalanine	10.5	12.4	16.4	14.6	17.7	12.6
Lysine	14.3	44.5	33.3	32.8	33.8	35.4
Histidine	4.8	13.7	11.6	11.3	12.7	13.2
Tyrosine		12.9	14.3	12.5	16.0	13.9
Fatty acids (% of total fatty acids; n = 2)						
C14:0		4.1	3.9	3.9	4.5	4.5
C15:0		0.4	0.4	0.5	0.7	0.8
C16:0		15.7	15.5	16.4	20.9	23.2
C16:1		3.7	3.7	3.7	4.0	4.0
C17:0		0.6	0.5	0.6	0.8	0.9
C18:0		3.7	4.0	4.5	6.2	7.6
C18:1 n-9		19.2	18.1	21.3	35.8	43.3
C18:2 n-6c		22.9	29.0	30.4	19.3	9.9
C18:3 n-3		0.7	0.7	0.5	-	-
C20:1 n-9		1.3	1.0	0.8	0.8	0.6
C20:4 n-6		0.5	0.5	0.5	-	-
C20:5 n-3		7.5	6.8	4.9	0.9	-
C22:6 n-3		10.8	9.6	7.2	1.6	-
Total n-3		19.1	17.2	12.6	2.5	-
Total n-6		23.4	17.2	30.9	19.3	9.9

[1] g per kg diet: manganese 60, iron 10, zinc 75, copper 5, cobalt 1, iodine 2.5, selenium 0.1, magnesium 65
[2] per kg diet: vitamin A 4000000 IU, vitamin D_3 600000 IU, vitamin E 40 g, vitamin K_3 2.4 g, vitamin B_1 5 g, vitamin B_2 8 g, niacin 50 g, Cal d-pantothenate 9 g, vitamin B_6 4 g, vitamin B_{12} 0.012 g, d-biotin 0.05 g, folic acid 1.4 g, vitamin C 40 g, inositol 40 g, antioxidant 25 g
[3] based on 20.9 kJ/g protein, 37.7 kJ/g lipid, 14.6 kJ/g carbohydrate (NRC, 1993)
[4] essential amino acid requirements for tilapia from Santiago and Lovell (1988)

and integrator using a fused silica capillary column SP 2380 (30 m × 0.25 mm inner diameter; 0.20 µm film), FID detector at 260°C, automatic injector at 240°C, and helium as the carrier gas. Column oven temperature conditions were: initial temperature of 120°C was held for 2 min, then increased by 5°C/min to 220°C and held constant for 15 min, then increased by 5°C/min to 240°C. Samples (1 µl) were injected into the column at a split rate of 1:50. Authentic fatty acid methyl esters were used for peak identification. Individual fatty acids were expressed as percentages of the total identified fatty acid methyl esters (FAME mix C4-C24 Supelco 18919-1 amp, Sigma, St. Louis, MO, USA).

Digestibility trial. Two weeks after the outset of the experiment, feces were carefully siphoned from each aquarium bottom on a daily basis. Uneaten feed was siphoned with a 2-cm pipe 20 min after feeding. Fecal samples were collected twice daily with a fine mesh netting (80 µm) 4 h after feeding in the morning and evening for 84 days, separately pooled in individual jars, and stored in a freezer (-20°C) until analysis. The samples were dried in an oven at 70°C for 24 h, ground with a grinder, and prepared for chemical analysis. Chromic oxide (Cr_2O_3) in the diets and fecal samples was estimated spectrophotometrically following the method of Furukawa and Tsukahara (1966). Apparent digestibility coefficients (ADC; %) were calculated according to Maynard and Loosli (1969) as ADC of the dry matter (%) = 100 - 100(%Cr_2O_3 in feed/%Cr_2O_3 in feces) and ADC of nutrients (%) = 100 - 100(%Cr_2O_3 in feed/%Cr_2O_3 in feces) x (%nutrient in feces/%nutrient in feed).

Growth trial. At the end of the experiment, survival (%), weight gain (g), specific growth rate (SGR; %/d), feed intake (g), feed conversion ratio (FCR), and protein efficiency ratio (PER) were determined for each replicate as survival = 100(final no. fish/initial no. fish), weight gain = mean final wt - mean initial wt, SGR = 100(ln mean final wt - ln mean initial wt)/feeding period, FCR = feed fed/wt gain, and PER = wt gain/protein intake. Viscera were removed to calculate the viscera somatic index (VSI; %) as 100(visceral wt/mean final wt); the liver was separated from the viscera to determine the hepatosomatic index (HSI; %) as 100(wet liver wt/mean final wt).

Statistical analysis. Data are presented as means±SEM of three replicates. Statistical analyses were performed using SPSS 14.0 (SPSS Inc., Chicago, IL, USA) for Windows. Data were subjected to one-way ANOVA followed by Duncan's multiple range test. Differences were considered significant at $p<0.05$ (Steel et al., 1996).

Results

Weight gain and specific growth rate of fish fed the 25% replacement diet did not significantly differ from those of fish fed the control diet (Table 3). The best FCR and PER were obtained in fish fed the 25% diet. There were no significant differences in HSI, but VSI was significantly higher in fish fed the 50% or 100% diets than in the other groups. The highest lipid and lowest ash contents were obtained in fish fed the 25% replacement diet. The apparent digestibility coefficients for protein were generally moderate while the ADC for lipid highly varied.

Table 3. Growth, feed utilization, composition, and apparent digestibility coefficients of Nile tilapia fry fed diets in which different levels of fishmeal were replaced by skate meal (means±SEM; n = 3).

	Diet (% replacement of fishmeal)				
	0 (Control)	*25*	*50*	*75*	*100*
Final body wt (g/fish)	20.0±2.1[a]	20.4±1.2[a]	12.2±0.3[b]	5.5±0.3[c]	5.6±0.4[c]
Wt gain (g/fish)	19.2±2.1[a]	19.6±1.3[a]	11.4±0.3[b]	4.7±0.2[c]	4.9±0.4[c]
Specific growth rate (%/day)	3.2±0.1[a]	3.3±0.0[a]	2.6±0.0[b]	1.7±0.1[c]	1.7±0.04[c]
Feed intake (g/fish)	25.6±2.0[a]	24.9±1.5[a]	18.2±0.3[b]	11.1±0.2[c]	10.8±0.4[c]
Feed conversion ratio	1.3±0.0[a]	1.2±0.0[a]	1.5±0.0[a]	2.3±0.1[b]	2.3±0.2[b]
Protein efficiency ratio	2.1±0.0[a]	2.3±0.0[a]	2.0±0.3[a]	1.5±0.4[b]	1.2±0.1[b]
Survival (%)	100.0±0.0	100.0±0.0	93.3±4.4	98.3±1.6	93.3±4.4
Viscerosomatic index (%)	11.4±0.3[a]	11.6±0.2[a]	11.6±0.4[a]	13.3±0.7[b]	13.2±0.2[b]
Hepatosomatic index (%)	2.5±0.2	2.5±0.1	2.3±0.1	2.1±0.1	2.3±0.1

Table 3 (cont.).

	Diet (% replacement of fishmeal)				
	0 (Control)	*25*	*50*	*75*	*100*
Proximate composition (% wet wt)					
Crude protein	19.98±0.3	19.83±0.2	20.14±0.1	19.82±0.1	19.84±0.1
Crude lipid	2.94±0.0^{bc}	3.16±0.0^{a}	3.11±0.0^{a}	3.05±0.0^{ab}	2.80±0.0^{c}
Crude ash	2.40±0.0^{b}	2.37±0.0^{b}	2.71±0.2^{ab}	3.17±0.1^{a}	2.78±0.0^{ab}
Dry matter	25.33±0.2	25.36±0.2	25.96±0.1	26.05±0.1	25.43±0.2
Fatty acid composition (% of total fatty acids)					
C14:0	3.2±0.0^{a}	2.9±0.0^{b}	2.9±0.0^{b}	3.0±0.0^{b}	2.9±0.1^{b}
C15:0	0.04±0.0^{b}	0.03±0.0^{b}	-	0.09±0.0^{b}	0.2±0.0^{a}
C16:0	19.1±0.2^{c}	19.5±0.1^{c}	23.8±0.5^{b}	29.0±0.0^{a}	28.9±0.3^{a}
C16:1	5.4±0.1^{c}	5.6±0.1^{c}	6.8±0.2^{b}	8.4±0.1^{a}	8.5±0.2^{a}
C17:0	0.1±0.0^{ab}	0.2±0.0^{a}	0.1±0.0^{ab}	-	-
C17:1c	0.2±0.1^{ab}	0.2±0.1^{ab}	-	0.1±0.0^{ab}	0.3±0.1^{a}
C18:0	3.7±0.0^{d}	4.1±0.0^{c}	4.8±0.1^{b}	5.8±0.1^{a}	5.9±0.0^{a}
C18:1n9	30.8±0.5^{d}	32.9±0.5^{c}	39.3±0.2^{b}	43.1±0.4^{a}	44.3±0.4^{a}
C18:2n6c	17.7±0.2^{b}	18.8±0.2^{a}	13.5±0.4^{c}	3.0±0.2^{d}	2.7±0.2^{d}
C:18:3n3	0.1±0.0^{a}	0.1±0.0^{ab}	-	-	-
C20:1n9	1.6±0.0^{b}	1.3±0.0^{c}	1.7±0.0^{b}	2.2±0.0^{a}	2.2±0.0^{a}
C20:4n6	1.0±0.1^{a}	0.8±0.2^{ab}	0.8±0.1^{ab}	0.3±0.1^{c}	-
C20:5n3	1.3±0.0^{a}	0.9±0.0^{b}	-	-	-
C22:6n3	10.3±0.1^{a}	8.1±0.1^{b}	4.0±0.2^{c}	1.3±0.0^{d}	0.7±0.1^{e}
C24:1	0.6±0.0^{a}	0.6±0.0^{a}	0.4±0.1^{a}	0.09±0.0^{b}	0.03±0.0^{b}
Total n-3	11.9±1.0^{a}	9.1±1.0^{b}	4.0±0.2^{c}	1.3±0.0^{d}	0.7±0.1^{d}
Total n-6	18.7±0.9^{a}	19.6±0.9^{a}	14.3±0.9^{b}	3.4±0.4^{c}	2.7±0.2^{c}
Apparent digestibility coefficients (%)					
Protein	77.4±1.7^{ab}	79.0±0.8^{a}	76.6±0.9^{ab}	75.6±0.2^{ab}	74.4±0.4^{b}
Lipid	84.6±0.0^{b}	88.2±0.2^{a}	84.1±0.4^{b}	81.3±0.8^{c}	80.9±0.9^{c}
Energy	77.4±0.2^{b}	79.2±0.6^{a}	77.0±0.8^{b}	77.3±0.4^{b}	76.1±0.2^{b}
Dry matter	51.2±0.7^{a}	51.5±0.2^{a}	47.5±0.4^{b}	47.8±0.3^{b}	44.2±0.3^{c}

Values in a row with different superscripts significantly differ (p<0.05).

Discussion

There were no significant differences in survival among Nile tilapia fed the experimental diets, indicating that the proportions of skate meal used to replace fishmeal were safe to consume. Results were similar in studies that evaluated the use of fishery by-catch and by-product ingredients alone or in combination to reduce fishmeal in diets for red drum (Li et al., 2004; Whiteman and Gatlin, 2005), rainbow trout (Hardy et al., 2005), tilapia (Goddard et al., 2008; Gumus et al., 2010; 2011), and sea bass (Altan et al., 2010). Growth performance was significantly altered by replacement of the fishmeal with skate meal; growth and nutrient utilization were not affected when 25% of the fishmeal was replaced but, beyond this level, weight gain, SGR, and PER were lower and FCR was higher than the control. Feed intake was lower in fish fed diets containing 75-100% fishmeal replacement than in fish fed the control or 25% diet, resulting in reduced growth and suggesting a palatability problem.

In comparison, weight gain and feed efficiency of red drum significantly decreased with increased levels of by-catch and by-product meals associated with shrimp trawling (Li et al., 2004; Altan et al., 2010) up to 75% of the dietary fishmeal could be replaced by sand smelt meal derived from local freshwater fisheries (Gumus et al., 2010). More than 60% fermented fisheries by-product meal and soybean curd residues included in diets for juvenile olive flounder (*Paralichthys olivaceus*) adversely affected growth and feed utilization (Sun et al., 2007) and up to 50% sablefish viscera meal can be used to partially replace fishmeal diets for Pacific threadfin (Ju et al., 2012). Shrimp head silage was economically substituted for fishmeal in tilapia feed without affecting the nutritional quality of the feed (Cavalheiro et al., 2007), Alaska white fishmeal was of suitable quality to replace fishmeal in diets for Pacific threadfin (*Polydactylus sexfilis;* Forster et al.,

2005), and skate meal was used to fully replace fishmeal in a diet for Pacific threadfin without adversely affecting growth performances (Ju et al., 2012).

The inferior growth performance and poorer feed utilization in fish fed diets containing more than 25% fishmeal replacement may have derived from differences in dietary amino acid and fatty acid compositions that may have lowered nutrient utilization by the tilapia fry. The essential amino acid and fatty acid values of our diets were lower than those reported, respectively, by Santiago and Lovell (1988) and Takeuchi et al. (1983) for Nile tilapia fry. Imbalance in the amino acid profiles may have been due to the skate meal, which was low in methionine.

Final whole body lipid profiles were closely related to the compositions of the respective diets, given that the essential fatty acid requirement of tilapia is only 0.5-1% (Takeuchi et al., 1983). There were major differences in the carcass analysis between treatments. Fatty acid deficiencies or imbalances due to low dietary levels of total n-3 and n-6 may have played a negative role on growth performance; the decrease in essential fatty acids in the fry carcass that accompanied the increase in replacement level suggests that the diets did not meet the essential fatty acid requirements of the tilapia and, hence, were poorly utilized. Growth was similarly depressed in other fish species when their diets contained high levels of fishery by-catch meal as an animal protein source (Babbitt, 1990; Hardy at al., 2005; Ju et al., 2012).

There were no significant differences in HSI between treatments. The HSI ranged 2.1-2.5, similar to earlier reports (Whiteman and Gatlin, 2005; Sun et al., 2007; Mohanta et al., 2011). The VSI of fish fed diets with more than 50% fishmeal replacement was significantly higher than that of fish fed the diets containing lower replacement levels.

Whole body lipid content was significantly lower in fish fed diets in excess of 25% replacement while whole body ash tended to increase with the increase of skate meal. Similarly, there were no differences in whole body protein and fat, but ash tended to increase in juvenile olive flounder fed increasing levels of a mixed meal consisting of fermented fishery by-products and soybean curd residues (Sun et al., 2007) and the carcass lipid of Pacific threadfin was significantly lower as the dietary content of skate meal and sablefish viscera meal increased (Ju et al., 2012). Whole body fat of fish fed diets containing fishery by-catch and processing waste meals increased in various fish (Whiteman and Gatlin, 2005; Goddard et al., 2008).

The ADC of protein varied 74.4-79.0%, somewhat lower than in red drum fed diets containing shrimp by-catch meal and Pacific whiting meal (79.1-81.4%; Li et al., 2004), rainbow trout fed diets with fish bone meal (84.5-89.7%; Lee et al., 2010), or blue gourami (*Trichopterus trichopterus*) fed diets containing surumi by-product meal (93.2-94.3%; Mohanta et al., 2011) as replacements for fishmeal. The ADC of lipid (80.9-88.2%) and energy (76.1-79.2%) were similar to the ADC of lipid (72.6-83.7%) and energy (75.7-86.4%) in red drum fed diets with shrimp by-catch and Pacific whiting meal (Li et al., 2004) but lower than the ADC of lipid (92.7-93.5%) and energy (90.3-92.5%) in blue gourami fed diets based on surumi by-product meal (Mohanta et al., 2011).

Our data indicate limited potential for skate meal to replace fishmeal as a protein source in fish feeds without modification of current processing methods. Growth data indicate that replacement of more than 25% of the dietary fishmeal with skate meal is not promising for tilapia fry as the ADC for dry matter, crude protein, lipid, and energy decreased as the replacement level increased. Thus, we conclude that 25% of the fishmeal in diets for Nile tilapia fry can be replaced by skate meal from fishery by-catches without adversely affecting growth performance. The effective utilization of fishery by-catch in aquafeeds requires further research to determine their potential use, cost effectiveness in practical feed formulations, and implementation procedures in the commercial fish feed industry. Commercial benefits derived from the fishery by-catches applied to meals for use in aquaculture should not, however, take precedence over attempts to reduce the quantities of by-catch and discarded fish by developing more selective fishing gear and improving the management of fisheries, especially since some types of skate fish are on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species.

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