

Use of shrimp protein hydrolysate in Nile tilapia (*Oreochromis niloticus*, L.) feeds

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Abstract A 45-day feeding trial was carried out to evaluate the use of shrimp protein hydrolysate (SPH) in diets for *Oreochromis niloticus*, L. SPH was included in isonitrogenous diets replacing fish meal protein by 0, 5, 10, and 20% and offered to Nile tilapia juveniles (1.7 ± 0.4 g) stocked in 40-L glass aquaria. The inclusion of SPH produced no significant differences ($P \geq 0.05$) in final weight, survival, weight gain, average daily gain, specific growth rate, feed conversion ratio, protein efficiency ratio, or apparent net protein utilization. The inclusion of SPH Nile tilapia diets significantly affected ($P < 0.05$) the final fish body composition. Protein and ash contents decreased and fat content increased slightly with the increase in SPH. This study has demonstrated that SPH is a promising protein feedstuff and could account for as much as 6% of Nile tilapia diets with no adverse effects on growth and nutrient utilization.

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Introduction

Aquaculture requires high-quality feeds with high protein content. Protein is generally the most expensive nutrient in aquafeeds. Marine protein sources (mainly fish and by-product meals) generally enhance the palatability of aquafeeds and are excellent sources of essential amino acids and fatty acids, vitamins, and minerals (Sudaryono et al. 1995; El-Sayed 1999; Hardy et al. 2007).

Fish meal remains the major dietary protein source, comprising between 20 and 60% of fish feed (Watanabe 2002). In the long term, many developing countries will be unable to depend on fish meal as a major protein source in aquafeeds. The determination of less expensive sources of protein that provide satisfactory growth is advantageous for diet manufacturers and aquaculture producers alike (Coyle et al. 2004).

Nile tilapia (*Oreochromis niloticus*, Linnaeus 1758) is one of the most cultured fish in tropical and subtropical regions in the world. The tilapia is an omnivorous species that has a digestive system that differs both from that of carnivorous and many herbivorous fish. It uses a wide spectrum of foods (Sklan et al. 2004a), efficiently uses dietary carbohydrates (Boscolo et al. 2002) and has a great ability to digest plant protein (Olvera-Novoa et al. 2002; Shelton and Popma 2006; Gatlin et al. 2007).

Many products have been tested as a protein source for tilapia, including soybean meal, *Leucaena* leaf meal (Wee and Wang 1987), feather meal (Bishop et al. 1995), shrimp, blood, meat and bone meals, poultry by-product meals (El-Sayed 1998), cottonseed meal (Mbahinzireki et al. 2001), sunflower cakes, anchovy meal, wheat bran (Maina et al. 2002), a mix of soybean meal, cottonseed meal, sunflower meal and linseed meal (El-Saidy and Gaber 2003), dried distillery grains with solubles (Coyle et al. 2004), corn gluten, rapeseed meal, sorghum, barley (Sklan et al. 2004b), soybean meal, maize gluten meal, dehulled flax, pea and canola protein concentrates (Borgeson et al. 2006). However, the inclusion of plant protein sources in aquafeeds is limited by their antinutritional factors associated to amino acid imbalances (Francis et al. 2001) and fiber levels (Olvera-Novoa et al. 1997).

Stimulated by increasing shrimp production from catches and farming, shrimp waste meal has been identified as an animal protein source of considerable potential (Fanimo et al. 2000) and could reduce environmental problems stemming from the improper dumping of the inedible parts of shrimp, such as heads, shells, and tails (Heu et al. 2003). However, the use of shrimp waste meal may be restricted due to its high fiber and ash contents (Cavalheiro et al. 2007), which have been found to reduce crustacean meal digestibility in tilapia (Köprücü and Özdemir 2005), decrease lipid absorption and increase water content in the feces of the Atlantic salmon, *Salmo salar* L. (Olsen et al. 2006).

Silva (2004) has produced a shrimp protein hydrolysate (SPH) from Pacific white shrimp, *Litopenaeus vannamei*, Boone (1931) heads, which is considered an excellent protein source due to its amino acid profile and low fiber content. Products obtained from shrimp processing wastes may serve as a useful source of protein and flavoring in food formulations mainly due to the level of free amino acids (Heu et al. 2003; Rutanapornvareesakul et al. 2005).

The aim of the present study was to evaluate the nutritional quality of SPH by assessing growth performance and protein utilization in Nile tilapia juveniles.

Materials and methods

Shrimp protein hydrolysate (SPH)

The SPH was produced through enzyme autolysis, based on the method described by Bezerra (2000). The raw material (shrimp heads) was washed and ground in distilled water (1:1). The blend was submitted to digestion in a water bath ($45 \pm 2^\circ\text{C}$, 3 h and slight agitation), with subsequent raise in temperature (100°C , 10 min) for enzyme deactivation. The solid and liquid fractions were separated by filtration (mesh: 1 mm^2) and centrifuged at $10,000\times g$ for 40 min. The obtained supernatant was defined as SPH (Fig. 1). The product was sent to the Protein Chemical Center of the Faculdade de Medicina de Ribeirão Preto, São Paulo, Brazil, for amino acid profiles and proximate composition. For these analyses, previously freeze-dried samples of SPH were used.

Diets

Four isonitrogenous (37% crude protein) and isocaloric ($440\text{ kcal } 100\text{ g}^{-1}$) experimental diets were formulated to feed *Oreochromis niloticus* juveniles (Tables 1, 2). SPH was added to the diets at 0 (control), 1.5, 3, and 6% inclusion levels, which corresponded to 0, 5, 10, and 20% of fish meal protein replacement. The SPH was incorporated to soybean meal and the dough was dried (65°C for 24 h). The ingredients were mixed and the diets prepared by extrusion under industrial conditions to obtain 1-mm diameter pellets. A commercial diet (COM, 36% crude protein) was used as reference.

Animals and experimental conditions

Sex-reversed Nile tilapia juveniles were obtained from the Aquaculture Station of the Universidade Federal Rural de Pernambuco. Groups of eight fish were stocked in each of

Fig. 1 Shrimp protein hydrolysate production schematic (modified from Bezerra 2000)

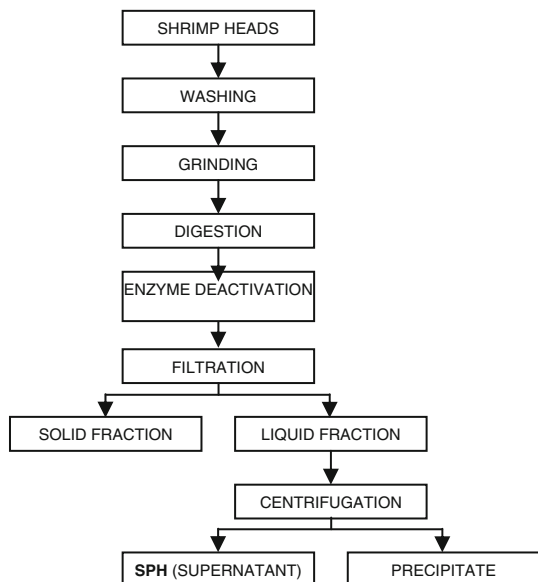


Table 1 Composition of the experimental diets

Ingredients (%)	Diets			
	SPH0	SPH5	SPH10	SPH20
Fish meal (57% CP)	23.0	22.0	21.0	18.0
Shrimp protein hydrolysate (SPH)	0.0	1.5	3.0	6.0
Soybean meal (40.4% CP)	47.0	47.5	47.5	47.5
Wheat meal	16.0	13.5	13.5	15.5
Corn starch	10.5	12.0	11.5	9.5
Soybean oil	1.0	1.0	1.0	1.0
Dicalcium phosphate	1.0	1.0	1.0	1.0
Mineral and vitamin mix ^a	1.0	1.0	1.0	1.0
Salt	0.5	0.5	0.5	0.5
Antioxidant BHT	0.02	0.02	0.02	0.02

CP crude protein, BHT butylated hydroxytoluene

^a Mineral and vitamin mix (quantity kg⁻¹ premix): vitamin A (20,000 UI), vitamin D₃ (5,000 UI), vitamin E (250 mg), vitamin K₃ (25 mg), vitamin B₁ (37.5 mg), vitamin B₂ (37.5 mg), vitamin B₆ (25 mg), vitamin B₁₂ (0.053 mg), vitamin C (250 mg), niacin (200 mg), pantothenic acid (100 mg), biotin (1.25 mg), choline (1,000 mg), inositol (250 mg), Fe (100 mg), Cu (12 mg), Zn (125 mg), Mn (37.5 mg), Se (0.25 mg), I (1.25 mg), Co (0.25 mg)

Table 2 Proximate analysis of the commercial and experimental diets

Proximate analysis (as-fed basis, g kg ⁻¹)	Diets				
	COM	SPH0	SPH5	SPH10	SPH20
Dry matter	918.0	944.8	935.9	936.5	946.7
Crude protein	345.6	371.9	374.3	376.2	380.6
Ether extract	65.0	48.1	56.2	52.1	55.9
Crude fiber	34.9	39.7	38.8	41.1	46.6
Ash	67.5	105.7	102.9	101.6	101.9
Nitrogen-free extract	487.0	434.6	427.8	429.0	435.0
Calcium	14.3	22.2	21.7	20.0	17.2
Phosphorus	11.3	12.4	12.5	12.6	12.8
Gross energy (kcal 100 g ⁻¹) ^a	461.5	438.3	444.5	442.2	431.8
P/GE ratio (mg kcal ⁻¹)	74.9	84.9	84.1	84.6	88.0

^a Estimate based on 5.65, 4.2 and 9.5 kcal g⁻¹ for proteins, carbohydrates and lipids, respectively

fifteen 40-L glass aquaria equipped with a biologic filter and continuous aeration. After a 7-day acclimatization period, diets were randomly assigned to three groups of fish. Fish were individually weighed (1.7 ± 0.4 g) and measured (4.7 ± 0.4 cm) before the onset of the feeding trial. Diets were offered four times a day (800, 1,100, 1,400 and 1,700 h) at an initial feeding rate of 15% of aquaria biomass. As it is generally recognized that younger or smaller fish consume more feed on a weight percentage basis than larger fish (Lim et al. 2006), the feeding rate was gradually reduced from 15 to 6% of the biomass. A sample of five fish per aquarium was weighed each 9 days for the determination of feeding rate adjustments.

Although no significant feed scrap was observed, the aquaria were siphoned twice daily and submitted to a 66% water exchange due to feces accumulation and the turbidity of the water. Water temperature, dissolved oxygen, pH, ammonia, and nitrite were monitored and averaged $28.7 \pm 0.59^{\circ}\text{C}$ (mean $\pm$ SD), 3.5 ± 0.92 , 8.1 ± 0.19 , 0.14 ± 0.22 and $0.08 \pm 0.02 \text{ mg L}^{-1}$, respectively.

Growth and nutrient utilization

Fish performance was evaluated through weight gain rate (WG), average daily gain (ADG), specific growth rate (SGR), feed conversion ratio (FCR), protein efficiency ratio (PER), and apparent net protein utilization (ANPU) based on the following formulae: $\text{WG (g)} = \text{BW}_f - \text{BW}_i$; $\text{ADG} = \text{WG (g)}/\text{time (days)}$; $\text{SGR} = 100 (\text{Ln BW}_f - \text{Ln BW}_i)/\text{time (days)}$; $\text{FCR} = \text{dry feed offered (g)}/\text{wet weight gain (g)}$; $\text{PER} = \text{wet weight gain (g)}/\text{protein fed (g)}$; and $\text{ANPU} = 100 [(\text{BW}_f \times \text{BCP}_f) - (\text{BW}_i \times \text{BCP}_i)]/(\text{TF} \times \text{CP})$, in which BW_i and BW_f = average initial and final body weight (g) of fish, respectively; BCP_i and BCP_f = initial and final body crude protein ($\text{g } 100 \text{ g}^{-1}$), respectively; TF = total amount of diet fed (g), and CP = crude protein of diet ($\text{g } 100 \text{ g}^{-1}$). Fish length and weight data were plotted (X and Y , respectively) to allow analysis of length–weight relationship, using the mathematical model $\text{Wt} = \Phi \text{Lt}^{\theta}$ to adjust the tendency of these plots (Santos 1978).

Analytical methods

At the end of the trial, all fish were weighed and two fish from each aquarium were sampled and frozen for the determination of body composition. Initial body composition analyses were performed on a pooled sample of eight fish that had been frozen prior to the study. Moisture, lipid, protein, and ash contents were determined using Standard Methods (AOAC 1990).

Statistical analysis

One-way analysis of variance (ANOVA) was used to test the effects of SPH inclusion to the diets on fish performance. Tukey's test was used at $\alpha = 0.05$ to test differences between treatment means when F -values from the ANOVA were significant. Length–weight relationship models were compared using the statistic W , which was compared to chi-square distribution at $\alpha = 0.05$ (Mendes 1999). Data obtained from the commercial diet were not used in the statistical analysis.

Results

Shrimp protein hydrolysate resulted in a product with 9.7% moisture, 43.63% crude protein, 6.25% ether extract, 7.32% ash, and 3,633 kcal/kg gross energy and a total amino acid content of 46.79 g/100 g (41.2% essential and 58.8% nonessential), mainly glutamate, aspartate, leucine, lysine, tyrosine, and arginine. The effects of SPH inclusion on tilapia performance and nutrient utilization are displayed in Table 3. The level of SPH incorporated into the diets (0, 1.5, 3, or 6%) did not affect ($P \geq 0.05$) final fish weight (27.18, 29.46, 26.02, and 25.19 g), weight gain (25.51, 27.73, 24.29, and 23.39 g), average daily

Table 3 Growth performance and nutrient utilization in Nile tilapia fed diets with increasing substitution of fish meal by shrimp protein hydrolysate (SPH) and a commercial diet (COM)

Diets	SPH0	SPH5	SPH10	SPH20	COM
Initial weight (g)	1.67 ± 0.14	1.73 ± 0.07	1.73 ± 0.09	1.80 ± 0.06	1.57 ± 0.07
Final weight (g)	27.17 ± 2.43 ^a	29.46 ± 1.05 ^a	26.02 ± 3.07 ^a	25.09 ± 2.49 ^a	16.40 ± 1.10
Survival (%)	100.0	100.0	100.0	100.0	100.0
WG (g) ¹	25.51 ± 2.57 ^a	27.73 ± 1.11 ^a	24.29 ± 3.04 ^a	23.39 ± 2.49 ^a	14.83 ± 1.12
ADG (g day ⁻¹) ²	0.57 ± 0.06 ^a	0.62 ± 0.03 ^a	0.54 ± 0.07 ^a	0.52 ± 0.06 ^a	0.33 ± 0.03
SGR (% day ⁻¹) ³	7.15 ± 0.34 ^a	7.38 ± 0.06 ^a	6.85 ± 0.39 ^a	6.73 ± 0.33 ^a	5.29 ± 0.22
FCR ⁴	1.15 ± 0.13 ^a	1.09 ± 0.09 ^a	1.14 ± 0.06 ^a	1.17 ± 0.07 ^a	1.28 ± 0.03
PER ⁵	2.26 ± 0.23 ^a	2.33 ± 0.21 ^a	2.21 ± 0.11 ^a	2.14 ± 0.13 ^a	2.08 ± 0.05
ANPU ⁶	39.31 ± 3.90 ^a	40.40 ± 3.64 ^a	38.59 ± 1.84 ^a	34.72 ± 2.08 ^a	32.08 ± 0.74

Values are mean ± SE of mean. Within a row, means with different superscript letters differ significantly ($P < 0.05$) by Tukey's test. Data obtained from the commercial diet were not used in the statistical analysis

¹ Weight gain rate, ² Average daily gain, ³ Specific growth rate, ⁴ Feed conversion ratio, ⁵ Protein efficiency ratio, ⁶ Apparent net protein utilization

gain (0.57, 0.62, 0.54, and 0.52 g day⁻¹) or specific growth rate (7.15, 7.38, 6.85, and 6.73% day⁻¹). Feed conversion ratio (1.15, 1.09, 1.13, and 1.17), protein efficiency ratio (2.26, 2.33, 2.20, and 2.14) and apparent net protein utilization (39.31, 40.39, 38.57, and 34.72) also were not affected by SPH inclusion.

The fish fed actively on all diets. Although the diets were offered four times a day, territorial behavior regarding feeding competition was observed, but no deaths were recorded during the feeding trial.

The parameters of the mathematical models for the evaluation of length–weight relationships of fish fed with different diets are displayed in Table 4. An analysis of these models revealed statistical differences ($P < 0.05$) in fish growth. Fish fed SPH5 (1.5% inclusion rate) exhibited the best length–weight relationship. Higher SPH inclusion levels (3 and 6%) did not contribute to fish growth, resulting in similar or worse growth performance than that provided by the SPH0 diet.

Figure 2 displays the evolution of the mean weight of Nile tilapia fed a commercial diet and diets containing 0, 5, 10, and 20% of SPH protein as partial substitute for fish meal protein. Mean weight of fish increased linearly throughout feeding trial. The experimental diets provided equal ($P \geq 0.05$) growth performances between one another.

Table 4 Parameters of the mathematical models ($Wt = \Phi L^{\theta}$) adjusted to length–weight data from fish fed diets with increasing inclusion levels of shrimp protein hydrolysate (SPH) and commercial diet (COM) over a 45-day feeding trial

Treatment	Φ	θ	R^2	n	C.S. ^a
SPH0	0.0134	3.1035	0.9919	129	b
SPH5	0.0132	3.1163	0.9950	126	a
SPH10	0.0142	3.0682	0.9924	128	b,c
SPH20	0.0149	3.0412	0.9933	125	c
COM	0.0163	2.9995	0.9889	127	–

^a Comparative statistics using statistic W compared to χ^2 distribution at $\alpha = 0.05$. Data obtained from the commercial diet were not used in the statistical analysis

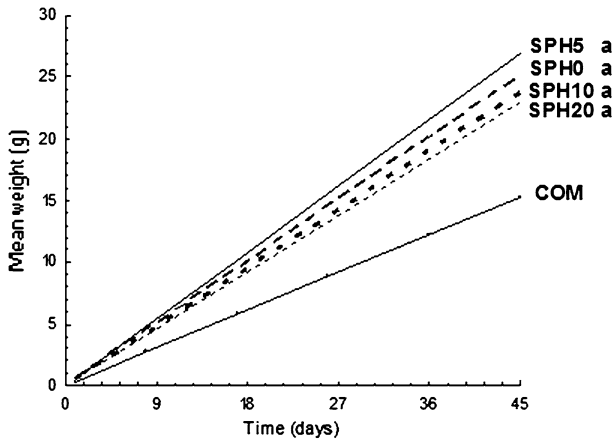


Fig. 2 Mean weight evolution of Nile tilapia fed diets with increasing shrimp protein hydrolysate (SPH) inclusion levels and commercial diet (COM) over a 45-day feeding trial. No significant differences were observed between treatments ($P > 0.05$). Data obtained from the commercial diet were not used in the statistical analysis

Table 5 displays the initial and final body compositions of whole fish. The inclusion of SPH in Nile tilapia diets significantly affected ($P < 0.05$) final fish body composition. Protein content decreased ($P < 0.05$) when SPH replaced 20% of fish meal. Fish fed SPH 10 and SPH 20 had greater fat content (58.4 and 59.8 g kg⁻¹, respectively) than fish fed the control diet (51.2 g kg⁻¹) or that with the lowest SPH inclusion level (50.3 g kg⁻¹). Fish fed the diet with no SPH had a higher ash content (40.5 g kg⁻¹) than those fed the other diets ($P < 0.05$).

Discussion

A number of authors have described the feasibility of using fishery by-catch and by-product as sources of animal protein for aquatic feeds (Goddard et al. 2003; Li et al. 2004;

Table 5 Initial and final proximate composition (g kg⁻¹ on as-fed basis) of whole body of Nile tilapia fed diets with increasing inclusion levels of shrimp protein hydrolysate (SPH) and commercial diet (COM) over a 45-day feeding trial

Fish	Dry matter	Protein ¹	Fat ¹	Ash ¹
Initial body composition	260.4	150.4	45.3	34.3
Final body composition				
SPH0	270.3	163.2 ± 1.2 ^a	51.2 ± 0.1 ^b	40.5 ± 0.1 ^a
SPH5	266.2	161.9 ± 1.5 ^a	50.3 ± 0.1 ^b	37.5 ± 0.1 ^b
SPH10	274.0	163.0 ± 3.6 ^a	58.4 ± 0.2 ^a	35.9 ± 0.2 ^b
SPH20	272.3	153.7 ± 1.4 ^b	59.8 ± 0.4 ^a	36.2 ± 0.1 ^b
COM	282.5	142.8 ± 1.6	89.0 ± 0.2	30.5 ± 0.1

¹ Each value is the mean (±SE of mean) of two replicates. Mean with common superscript in the same column are not significantly different ($P < 0.05$). Data obtained from the commercial diet were not used in the statistical analysis

Goddard and Perret 2005; Whiteman and Gatlin III 2005). Plascencia-Jatomea et al. (2002) concluded that shrimp protein silage could be included in tilapia diets at concentrations as high as 15%, improving fish growth rate. The present study demonstrated that 6% of SPH can be included in diets for Nile tilapia without reducing growth performance.

In fact, there is a remarkable difference between production methods of the shrimp silage used by the above-cited authors and the SPH used in the present study. SPH was produced by autolysis in the present study, with no use of any exogenous chemical or biologic additive, which is common in silage processes. Plascencia-Jatomea et al. (2002) report that the acidic conditions in which fermentative shrimp silage hydrolysate is produced causes the loss of labile nutrients such as tryptophan. Although the two products have a very similar essential amino acid (EAA) composition, the SPH produced here proved to be an adequate source of tryptophan, with 3.5, 3.5, and 1.75–2.4-fold higher levels of tryptophan than fish, shrimp and soybean meals, respectively (Table 6).

Similarly, SPH seemed to be a good source of other EAAs, especially lysine, leucine, arginine, phenylalanine, and valine. Methionine levels (an important limiting amino acid for fishes) were 4.5–5.7, 3 and 1.5–2.5-fold higher than those in soybean, shrimp, and fish meals, respectively. Results concerning methionine and lysine levels are particularly important in aquaculture, as supplementation of diets with these amino acids is often required when alternative sources of protein are used as fish meal replacements (Cheng et al. 2003; Alam et al. 2005; Forster and Dominy 2006; Sardar et al. 2008). The inclusion of only 6% of SPH in the diet (Table 6) can supply 6–13% of the EAA requirement for the tilapia described by Santiago and Lovell (1988).

Table 6 Comparison of amino acid (AA) composition of shrimp protein hydrolysate (SPH) and other ingredients used in aquatic feeds, expressed as percentage of dietary protein

Essential amino acids	Fish meal		Soybean meal		Shrimp meal ^a	Shrimp head silage		SPH ^c	Tilapia AA requirement ^f	% DV ^g
	a	b	a	b		c	d			
Arginine	3.78	4.45	3.05	3.11	2.79	6.26	7.50	7.30	4.20	10.43
Histidine	1.40	1.21	1.25	1.12	1.07	2.33	1.61	2.30	1.72	8.02
Isoleucine	2.15	1.84	1.75	2.42	1.86	3.16	2.64	4.30	3.11	8.30
Leucine	3.77	3.55	2.91	2.85	2.98	6.65	4.11	7.40	3.39	13.10
Lysine	3.98	4.03	2.57	2.67	2.41	7.36	7.35	7.20	5.12	8.44
Methionine	1.80	1.10	0.47	0.60	0.91	1.86	2.62	2.70	2.68	6.04
Phenylalanine	1.81	1.93	1.91	2.33	1.76	4.20	2.35	5.10	3.75	8.16
Threonine	1.99	2.32	1.51	1.88	1.58	6.30	2.13	4.50	3.75	7.20
Tryptophan	0.39	–	0.80	0.58	0.40	–	0.96	1.40	1.00	8.40
Valine	2.59	2.47	1.90	2.24	2.03	4.23	2.98	4.80	2.8	10.29

^a Halver (1995) (from INFIC data base)

^b Embrapa (1989) (from Brazilian feedstuffs)

^c Plascencia-Jatomea et al. (2002)

^d Nwanna et al. (2004)

^e Present study (Tyrosine: 7.3, Aspartic acid: 9.2, Glutamic acid: 12.5, Glycine: 6.2, Serine: 4.3, Alanine: 6.7, Proline: 6.5, Cysteine: 0.9)

^f Santiago and Lovell (1988), based in a 28% crude protein diet

^g Percentage of daily values of tilapia requirement of amino acids provided by the inclusion of 6% SPH in diet

The separation of shrimp carapaces by the filtration step during SPH production (Fig. 1) removes the chitin, which is a significant antinutritional factor associated with poor fish growth and is present in large amounts in products derived from crustaceans and insects (Shiau and Yu 1999; Ogunji et al. 2008). The supernatant provided after filtration and centrifugation steps (SPH) contained high levels of small peptides (unpublished data), which render the product highly soluble. The inclusion of 6% of SPH in the diet corresponds to about 20% of fish meal replacement, which is an important finding, as fish meal is a limiting ingredient in aquatic feeds, whereas SPH is produced from shrimp processing waste.

Nutrient utilization and growth performance of fish fed the experimental feeds were not significantly different ($P \geq 0.05$), meaning that the four experimental diets had enough quality to assure satisfactory growth of the fish. The maximum percentage of survival recorded also reflected the adequate handling and experimental conditions. Although data obtained from the commercial diet were not used in the statistical analysis, the experimental diets produced evidently better results regarding growth and feed utilization. Even though there are remarkable differences between experimental conditions, such as initial weight of fishes, target species or even culture period, a better performance of fish fed SPH in the present work was observed when compared to those reported by Plascencia-Jatomea et al. (2002), Nwanna et al. (2004) (Table 7). These authors also found that shrimp silage can replace 15 and 20% of fish meal, respectively with no adverse effects on growth and feed efficiency.

Fish feeds should be formulated based on the nutritional requirements of the target species, but this is not the only characteristic to consider. Feed acceptance depends upon other important aspects such as appearance, particle size and organoleptic properties related to smell, taste and texture (Jobling et al. 2001), and these characteristics can be influenced by the choice of feed ingredients and processing conditions. According to Higuera (2001), the feeding stimulants that cause the greatest behavioral responses in fishes are those composed of free amino acids, nucleotides, nucleosides, and quaternary ammonium bases. Stimulant products should have low molecular weight and be nitrogen-containing, nonvolatile, amphoteric, water-soluble, stable to heat treatments, and have

Table 7 Growth performance of fish fed diets with different marine protein sources as fish meal replacement

Parameters	SPH ^a	SHS ^b	SHS ^c	FM ^d
Initial weight (g)	1.67–1.80	0.296–0.340	12.1–12.2	4.9–5.3
Final weight (g)	25.09–29.46	1.57–2.43	28.6–32.8	26.6–33.5
Weight gain (g)	23.4–27.7	1.27–2.09	16.5–20.7	21.7–28.6
Weight gain (%)	1,301–1,624	429–616	134–171	521–659
Time (days)	45	56	84	63
Average daily gain (g day ⁻¹)	0.52–0.62	0.023–0.037	0.20–0.25	0.35–0.45
Specific growth rate (% day ⁻¹)	6.7–7.4	1.3–1.5	1.0–1.2	2.7–3.1
Feed conversion ratio	1.1–1.2	1.9–2.2	2.5–2.8	1.3–1.4
Protein efficiency ratio	2.1–2.3	1.6–1.9	0.4–0.52	1.8–1.9
Survival (%)	100	93–100	–	97–99

^a Shrimp protein hydrolysate: present study

^b Shrimp head silage: as fish meal replacement in Nile tilapia diet (Plascencia-Jatomea et al. 2002)

^c Shrimp head silage: as fish meal replacement in *Clarias gariepinus* diet (Nwanna et al. 2004)

^d Fishery by-catch and processing waste meals in Nile tilapia diet (Goddard et al. 2008)

broad biologic distribution. Alanine, glycine, proline, valine, tryptophan, tyrosine, phenylalanine, lysine, and histidine appear to be major components of feeding stimulants for many fish species. Based on the amino acid composition of SPH (Table 6) and fish behavior when SPH-based diets were offered (diets were avidly consumed), it was concluded that SPH could also be used as flavoring in tilapia feeds.

The territorial behavior observed in all treatments could have caused heterogeneous growth of the tilapia. Fernandes and Volpato (1993) report that increase in heterogeneous growth as a result of grouping in the Nile tilapia may be associated to the social stress imposed by dominant fish on subordinates. This stress may decrease the energy available for growth. Social hierarchy generally leads to different degrees of access to available feeds on the part of individual fish (Alanärä and Brännäs 1996; Hakoyama and Igushi 1997). According to Kestemont and Baras (2001), better competitors generally achieve earlier access to food, digest their first meal and feed again before the end of feeding period, whereas subordinate fish do not have this opportunity, which results in growth heterogeneity.

Although SPH inclusion resulted in carcass fat deposition (Table 5), even the greatest value (59.8 g kg^{-1}) was smaller than that observed in fish fed the commercial diet. These results are similar to those reported by Plascencia-Jatomea et al. (2002), who found body crude lipid content ranging from 53.6 to 67.2 in Nile tilapia fed diets containing shrimp head hydrolysate by fermentative silage. Whole body composition reflected diet composition only with regard to ash content. As SPH inclusion increased in experimental diets, the ash body content decreased. This was the result of the combined effects of low ash content in SPH and gradual reductions on amounts of fish meal employed.

Conclusion

The results of SPH amino acid composition and growth data suggest that SPH is a promising protein feedstuff for the Nile tilapia. SPH can be included up to 6% in the diets for Nile tilapia juveniles (20% of fish meal replacement) with no adverse effects on growth and nutrient utilization. Further research is required to evaluate higher SPH inclusion and the influence on the digestive enzyme profile and economic value.

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