

Digestibility and feeding value of some feed ingredients fed to tilapia *Oreochromis niloticus* (L.)

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Abstract

The apparent digestibility of protein, organic matter and energy of high-fibre and fibre-reduced sunflower cakes, Kenya's 'omena' fishmeal, anchovy fishmeal and wheat bran were investigated in tilapia *Oreochromis niloticus* (L.) fingerlings. The feeding values and protein qualities of the above ingredients were also determined at two dietary protein levels. Fourteen diets were formulated, and each was provided to three tanks containing 12 fish in Expt 1 (digestibility study) and 25 fish in Expt 2 (feeding trial). Water temperatures and dissolved oxygen concentrations were maintained above 26 °C and 5.5 mg L⁻¹ respectively. Anchovy and 'omena' fishmeals each had an apparent digestibility coefficient for protein (ADC-P) of 90%, whereas the fibre-reduced and high-fibre sunflower cakes had ADC-P values of 89% and 86%. Wheat bran had an ADC-P value of 75%, which was significantly lower than those found for the other test ingredients. Apparent digestibility coefficients for energy (ADC-E) and digestible energy values (DE) were 86% and 78% and 4003 kcal kg⁻¹ and 3624 kcal kg⁻¹ for anchovy and omena fishmeals respectively. The corresponding values for the plant protein sources were 42% and 30% and 2200 kcal kg⁻¹ and 1400 kcal kg⁻¹ for the fibre-reduced and high-fibre sunflower cakes respectively. Diets based on the fibre-reduced cake had higher levels of all amino acids than those based on the

high-fibre cake. Fish fed diets with 30% protein gained 40 g and had a feed conversion ratio (FCR) of 1.87, whereas those fed diets with 20% protein gained 35 g and had a FCR of 2.2. The source of protein had a significant effect on weight gain.

Keywords: anchovy fish meal, high-fibre sunflower cake, low-fibre sunflower cake, omena fishmeal

Introduction

To formulate practical diets for fish, the nutrient compositions of the feedstuffs that are potential ingredients for inclusion in such diets and the biological availability of the nutrients and energy in each of the ingredients for the species under consideration must be known. Diets for intensive fish culture are formulated where possible on the basis of literature values for digestible energy and protein in the feedstuffs. For some warm-water fish such as tilapia, however, comprehensive tables showing the digestibility coefficients for nutrients and energy from various ingredients are not available. Consequently, diets for tilapia are formulated using published data from other warm-water fish species such as carp *Cyprinus carpio* (L.) and catfish *Clarias gariepinus* (Burchell).

Tilapia are herbivorous fish that possess morphological and physiological adaptations for the

utilization of diets high in fibre. This aspect of their feeding habits has not been fully exploited in commercial aquaculture. Most formulated feeds for tilapia resemble those for omnivorous fish, in that they contain significant levels of animal proteins (Hughes & Handwerker 1993). Much research has been done to evaluate non-traditional protein sources partially or wholly to replace fishmeal in diets for all types of fish. Among the plant protein sources, soybean meal has been used widely because of its good amino acid profile, which, as the main source of proteins, supports the growth of many fish species (Viola & Arieli 1983; Wilson & Poe 1985; Shiau, Chuang, & Sun 1987). Soybeans, however, are not suitable for growing in many countries; hence the need to evaluate other plant protein feedstuffs.

Sunflower cake contains few or no known anti-nutritional factors. Sunflower is cultivated extensively because of its adaptability to a wide range of climatic and soil conditions (Ravindran & Blair 1992). Its seeds are inexpensive to process, and the cake remaining after oil extraction is used as a protein supplement in animal diets (Daghir, Ras & Wwayjan 1980). The potential use of sunflower cake in fish diets is limited by its high fibre content. Crude fibre not only has no known dietary value for fish, but it also dilutes digestible nutrient densities, thus increasing the release of polluting wastes into the environment.

The objectives of this study were to determine the effect of reducing fibre content in sunflower cake on

the apparent digestibility of protein, energy and organic matter, and to compare the digestibility of Kenyan omena fishmeal with that of prime-quality anchovy fishmeal, using tilapia *O. niloticus* (L.) as the test animal. Also of interest was to compare the nutritional values and protein qualities of diets based on high-fibre and fibre-reduced sunflower cakes, and omena and anchovy fishmeals when fed to *O. niloticus* at two levels of dietary protein. All the experiments were done at the University of Nairobi in Kenya.

Materials and methods

Feed ingredients

The chemical compositions of the ingredients used are shown in Table 1. Hybrid sunflower seeds were purchased from a commercial trader (Rift Valley Products, Nakuru, Kenya).

The seeds were partly dehulled using a manually operated Cecoco dehuller (Ibaraki, Osaka, Japan). The oil content of the seeds was reduced by a commercial screw press oil extractor (Gold Feeds, Nairobi, Kenya). The high-fibre cake was a commercial cake that is marketed as a prime-quality sunflower cake. Omena fishmeal was purchased from Tamfeeds, Nairobi, Kenya. It was made from a cypriid fish, *Rastrineobola argentea*. The anchovy fishmeal was a high-quality Chilean low-temperature (LT) meal purchased from Moore-Clark/Nutreco, Vancouver, BC, Canada. Cellulose and cornstarch

Table 1 Chemical compositions of the ingredients used in Expts 1 and 2 (air-dry basis)*

Ingredients†	Anchovy FM		Omena FM		F-R SFC		H-F SFC		SBM‡	WB	Wheat
	1	2	1	2	1	2	1	2			
DM (%)	92.00	90.00	90.00	92.00	92.00	91.00	92.00	91.00	89.10	89.40	89.00
Protein (%)	65.10	65.00	56.60	55.00	41.40	39.00	27.40	28.00	43.20	15.20	11.50
Lipid (%)	9.60	9.60	12.00	13.50	10.40	22.20	8.90	8.92	2.00	4.50	1.20
Ash (%)	15.30	15.30	17.50	–	8.90	–	9.80	–	6.50	3.50	–
CF (%)	1.50	1.50	0.90	–	11.40	10.40	26.70	27.00	4.60	8.70	1.30
ADF (%)	–	–	–	–	12.60	12.65	22.50	20.50	9.30	11.90	NA
NDF (%)	–	–	–	–	23.60	21.80	45.00	42.00	14.10	25.50	NA
GE (kcal kg ⁻¹)	4.41	4.47	4.50	4.61	4.61	4.70	4.57	4.51	4.09	4.34	3.99
Ca (%)	3.60	\$NA	3.60	NA	0.40	NA	0.40	NA	0.40	0.10	NA
P (%)	2.30	NA	2.20	NA	1.30	NA	1.00	NA	0.60	1.00	NA

*DM, dry matter; CF, crude fibre; ADF, acid detergent fibre; NDF, neutral detergent fibre; GE, gross energy; Ca, calcium; P, phosphorus.

†FM, fishmeal; F-RSFC, fibre-reduced sunflower cake; HF-SFC, high-fibre sunflower cake; SBM, soybean meal; WB, wheat bran.

‡The same batch of soybean meal was used in both experiments.

\$NA, not analysed.

were bought from ICN, Canada, and chromic oxide from Fisher Scientific, Ontario, Canada.

Experimental diets

Fourteen diets (Table 2 and Table 3) were formulated. In the digestibility assessment study, a reference diet based on prime-quality anchovy fishmeal, soybean meal, wheat bran and corn starch was formulated. Gross energy, crude protein and ADF values [dry matter (DM) basis] in the diet were 4890 kcal kg⁻¹, 34.6% and 12.1% respectively. Test diets were made by combining 70% of the reference diet with 30% of each of the test ingredients (high-fibre and fibre-reduced sunflower cakes, 'omena fishmeal', anchovy fishmeal and wheat bran) (Table 3). Eight diets in which LT anchovy fishmeal, omena fishmeal, high-fibre and fibre-reduced sunflower cakes were the major sources of protein were used in Expt 2. In the diets based on anchovy and omena fishmeals, the fishmeals

provided most of the dietary protein, whereas in the diets based on sunflower cakes, 50% of the dietary protein was provided by the cakes, and the remaining 50% was mainly provided by anchovy fishmeal (Table 3). Feedstuffs were mixed in a feed mixer (Balton CP Ltd, Alan Pearce, Watford, Herts, UK) and pelleted using an Ottevanger pelleting machine (Ottevanger Machine Fabrieken, Moekapelle, Holland). Each diet contained one of two levels of protein, approximately 20% or 30%. At each protein level, the diets were formulated to contain similar levels of digestible energy by varying the level of corn oil in the diet. In calculating the digestible energy contents of the diets, the apparent digestibility coefficients used were as follows: anchovy fishmeal, 86% (Anderson, Capper & Bromage 1991; Hanley 1987); omena fishmeal, 78% (present study). The digestible energy concentrations of cornstarch and corn oil were taken as 2700 kcal kg⁻¹ DM (NRC 1993; for channel catfish) and 8100 kcal kg⁻¹ DM (Santiago & Reyes 1993) respectively.

Table 2 Chemical compositions of the diets used in Expt 1 (air-dry basis)

	Reference diet	Fibre-reduced SFC*	High-fibre SFC	Omena fishmeal	Anchovy fishmeal	Wheat bran
Ingredients (%)						
Fibre-reduced SFC	–	30.00	–	–	–	–
High-fibre SFC	–	–	30.00	–	–	–
Anchovy fishmeal	37.8	26.46	26.46	26.46	56.46	26.46
Omena fishmeal	–	–	–	30.00	–	–
Soybean meal	10.0	7.00	7.00	7.00	7.00	7.00
Wheat bran	10.0	7.00	7.00	7.00	7.00	37.0
Corn starch	25.4	17.80	17.80	17.80	17.80	17.80
Cellulose	10.0	6.83	6.83	6.83	6.83	6.83
Corn oil	2.0	1.40	1.40	1.40	1.40	1.40
Ascorbic acid	0.7	0.49	0.49	0.49	0.49	0.49
Vit/min premix†	3.5	2.45	2.45	2.45	2.45	2.45
Chromic oxide	0.5	0.50	0.50	0.50	0.50	0.50
Choline chloride (50%)	0.1	0.07	0.07	0.07	0.07	0.07
Determined analyses (DM basis)						
Dry matter (%)	90.7	89.4	89.0	90.5	88.7	89.1
Gross energy (kcal kg ⁻¹)	4890	4954	4892	4807	4812	4882
Crude protein (%)	34.6	37.9	34.4	41.8	44.6	31.1
Ether extract (%)	8.4	10.1	9.6	10.6	7.2	7.6
ADF (%)	12.1	13.8	17.3	16.2	9.0	13.5
Ash (%)	7.7	8.3	7.8	9.9	11.0	6.7

*SFM, sunflower cake.

†The vitamin/mineral premix provided the following per kilogram of feed: vitamin A, 6544 IU; vitamin D3, 4000 IU; vitamin E, 165 IU; vitamin B12, 0.03 mg; vitamin K, 3 mg; riboflavin, 70 mg; folic acid, 9 mg; nicotinic acid, 192 mg; pantothenic acid, 60 mg; biotin, 0.4 mg; vitamin B1, 10 mg; vitamin B6, 25 mg; copper, 35 mg; iodine, 9 mg; zinc, 35 mg; manganese, 35 mg; selenium, 0.4 mg.

Table 3 Compositions of the diets used in Expt 2

Diets*	20% Protein				30% Protein			
	OM O-20	AM A-20	F-R SFC-20	H-F SFC-20	OMO-30	AM A-30	F-R SFC-30	H-F SFC-30
LT Anchovy fishmeal	–	30.0	13.2	13.5	–	44.0	20.9	20.9
Omena fishmeal	33.7	–	–	–	52.0	–	–	–
Fibre-reduced SFC	–	–	26.1	–	–	–	38.5	–
High-fibre SFC	–	–	–	35.7	–	–	–	53.6
Corn starch	34.9	34.2	36.9	27.6	12.7	16.9	22.9	–
Whole wheat flour	12.6	13.0	12.6	12.6	12.0	13.0	12.2	12.6
Cellulose	12.6	15.7	4.0	–	18.3	20.1	–	–
Corn oil	2.2	3.7	1.6	5.0	2.5	3.6	0.4	7.8
Ascorbic acid	1.0	1.0	0.9	0.9	1.0	1.0	0.9	0.9
Vit/mineral premix†	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9
Dicalcium phosphate	1.5	1.0	3.2	3.2	–	–	2.8	2.8
Iodized salt	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Choline chloride (50%)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Proximate and mineral composition (DM basis)‡								
DM (%)	90.00	91.44	91.19	91.17	92.04	92.56	91.56	91.62
DE (kcal kg ⁻¹) (calculated)	2961	2965	2814	2751	3077	3050	2915	2797
Protein (%)	20.05	22.50	23.60	21.90	29.10	33.00	33.80	33.0
Crude fat (%)	9.60	8.30	12.61	10.40	12.40	10.40	14.70	15.80
ADF (%)	13.20	17.30	7.00	7.70	17.60	25.10	5.60	12.00
NDF(%)	22.20	31.80	12.30	17.40	26.10	37.80	12.30	23.70
Ash (%)	7.00	6.80	6.90	–	8.50	8.40	7.80	8.00
Ca (%)	1.90	1.90	1.60	1.60	1.90	2.00	1.70	1.70
P (%)	1.60	1.60	1.50	1.40	1.70	1.80	1.50	1.50

*OM, omena fishmeal; AM, anchovy fishmeal; F-R SFC, fibre-reduced sunflower cake; H-F SFC, high-fibre sunflower cake; 20% and 30% refer to protein levels.

†The vitamin/mineral premix provided the following per kilogram of the diet: vitamin A, 6000 IU; vitamin D3, 600 IU; vitamin E, 100 mg; vitamin K3, 3 mg; vitamin B1, 10 mg; vitamin B2, 20 mg; niacin, 150 mg; D-pantothenic acid, 50 mg; vitamin B6, 10 mg; vitamin B12, 0.03 mg; folic acid, 4 mg; biotin 0.8 mg; choline, 600 mg; vitamin C, 600 mg; inositol, 300 mg; manganese, 192 mg; iron 51.2 mg; copper, 6.4 mg; zinc, 57.6 mg; selenium, 0.15 mg; traces of cobalt and iodine.

‡All values were determined by analysis except for DE, which was estimated from published data (see text).

Chemical analyses

All ingredients and experimental diets were analysed in duplicate for their content of dry matter, ash, crude fibre, fat and protein according to standard procedures (AOAC 1984). Chromic oxide in the diets and faeces was determined by the acid digestion method of Farukawa & Tsukahara (1966). Amino acids were analysed as described by AOAC (1998). Performic acid oxidation was carried out before hydrolysis to oxidize cystine and methionine to cysteic acid and methionine sulphone respectively. Sodium metabisulphite was added to neutralize the performic acid. Amino acids were released from protein by hydrolysis with 6 N HCl. Hydrolysed samples were diluted with sodium citrate buffer and pH adjusted to

2.2. Individual amino acids were quantified using high-performance liquid chromatography (HPLC) (Sedgwick, Fenton & Thompson 1991). Tyrosine and tryptophan could not be determined in this way.

Faecal collection

Faeces were collected by stripping (Nose 1960) once a fortnight in the first 50 days of the experiment, and once every week for the next 56 days to the end of the study. Fish were fed at 08.30 and 10.30, and faecal collection was done \approx 5–7 h after the first feeding. All fish in a tank were first anaesthetized with MS 222. Faeces from each tank were dried immediately after collection at 60 °C for a period of 24 h. They were labelled and frozen until

the end of the trial, when all faeces from each tank were pooled. Faecal samples were analysed for moisture, chromic oxide, protein, gross energy and ash.

Digestibility assessment

Apparent digestibility coefficients of the test diets and test ingredients were calculated by the indicator method of difference described by Maynard, Loosli, Hintz & Warner (1979). Apparent digestibility coefficients (%) for each of the six test diets and test ingredients were determined for crude protein, gross energy and organic matter. The apparent digestibility coefficient for a nutrient in a test ingredient was calculated from the digestibility coefficient for the reference diet and the test diets according to the following equation of Forster (1999).

$$ADCN_{\text{ing}} = [(a + b) * ADCN_{\text{com}} - (a) * ADCN_{\text{ref}}] / b$$

$ADCN_{\text{ing}}$ = apparent digestibility of a nutrient in the test ingredient;

a = nutrient contribution of the reference diet to the nutrient content of the combined diet = (% nutrient in reference diet) * (100–I);

b = nutrient contribution of test ingredient to nutrient content of the combined diet = (% nutrient in test ingredient) * I;

I = percentage of test ingredient in the combined diet;

$ADCN_{\text{com}}$ = apparent digestibility coefficient of a nutrient in the diet consisting of a combination of reference diet and test ingredient;

$ADCN_{\text{ref}}$ = apparent digestibility coefficient of a nutrient in the reference diet.

Fish sampling

Oreochromis niloticus fingerlings were purchased from Baobab Fish Farm (Bamburi Nature Trail, Mombasa, Kenya), and transferred to the University of Nairobi for these experiments. They were acclimated to laboratory conditions for a period of 3 weeks. During the acclimation period, they were fed on commercial feed (Baobab tilapia pellets). After this period, they were weighed and allocated to experimental circular tanks, with a diameter of 1 m and filled with water to a depth of 0.26 m. The fish weighed at $59 \text{ g} \pm 5$ (\pm SD) at the start of Expt 1 and $16 \text{ g} \pm 3$ at the start of Expt 2. Each dietary treatment was replicated three times, with 12 fish

per tank in Expt 1 and 25 fish per tank in Expt 2. Water level was adjusted as the fish biomass increased to maintain a stocking density below 0.1 kg of fish per litre of water. Water temperature and dissolved oxygen concentration were maintained at $26^\circ\text{C} \pm 2$ and above 5.5 mg L^{-1} respectively. The water in each tank was changed completely after 48 h. The fish were kept under a natural photoperiod (Nairobi, Kenya, $1^\circ 16' \text{ S}$, $36^\circ 48' \text{ E}$).

Data were analysed using Proc GLM from the SAS statistical package. Means were compared using Tukey's multiple range test, and the level of significance was set at $P < 0.05$.

Results

Dehulling sunflower seeds considerably reduced the fibre content and increased the percentage of protein in the cake relative to the dehulled seeds (Table 1). Dehulled sunflower cakes are difficult to press using the conventional screw press machines and, consequently, the fibre-reduced cakes, especially in Expt 2, had a slightly higher lipid content than the high-fibre cakes. The low-protein diets in Expt 2 were formulated to contain a DE concentration of $2800 \text{ kcal kg}^{-1}$ and a protein content of 20% (DM basis). The high-protein diets were formulated to contain a DE concentration of $3000 \text{ kcal kg}^{-1}$ and a crude protein content of 30% (DM basis). Calculated DE concentrations (DM basis) in the low-protein diets ranged from $2751 \text{ kcal kg}^{-1}$ in the diet based on the high-fibre sunflower cake (HFSC-20) to $2965 \text{ kcal kg}^{-1}$ in the diet based on anchovy fishmeal (Table 3). The calculated DE concentrations in the high-protein diets ranged from $2797 \text{ kcal kg}^{-1}$ to $3077 \text{ kcal kg}^{-1}$. The lower DE concentrations in the diets based on the high-fibre cake resulted from an overestimation of the DE concentration of the cake during the formulation of the diets. The low-protein diets were formulated to contain a lower DE concentration than the high-protein diets in order to minimize differences in energy: protein ratios between the diets at the two protein levels. The amino acid profiles of the diets used in Expt 2 are shown in Table 4. When the amino acids were expressed as a percentage of dietary protein, diets based on the two fishmeals had a profile that was almost similar. The diets based on the two sunflower cakes had lower levels of lysine and threonine than those based on the fishmeals.

Table 4 Amino acid compositions of the diets used in Expt 2 (expressed as g 100 g⁻¹ DM and as a percentage of the dietary protein*)

Protein level Diets†	20% protein				30% protein				Tilapia requirements (NRC 1993)			
	O-20	A-20	F-R	H-F	O-30	A-30	F-R	H-F	(% of the diet)	(% of protein)		
Arginine	0.94 (4.70)	1.01 (4.49)	1.13 (4.79)	0.98 (4.47)	1.43 (4.91)	1.44 (4.36)	1.52 (4.50)	1.67 (5.06)	1.26	4.20		
Histidine	0.37 (1.84)	0.49 (2.18)	0.49 (2.08)	0.42 (1.92)	0.55 (1.89)	0.59 (1.80)	0.66 (1.95)	0.59 (1.79)	0.52	1.72		
Isoleucine	0.73 (3.63)	0.83 (3.70)	0.77 (3.26)	0.67 (3.06)	1.10 (3.78)	1.09 (3.30)	1.07 (3.17)	0.92 (2.79)	0.93	3.11		
Leucine	1.24 (6.17)	1.41 (6.27)	1.24 (5.25)	1.11 (5.07)	1.90 (6.53)	1.92 (5.82)	1.75 (5.18)	1.51 (4.58)	1.02	3.39		
Lysine	1.33 (6.62)	1.49 (6.62)	1.06 (4.49)	0.94 (4.29)	2.05 (7.04)	2.06 (6.24)	1.59 (4.70)	1.32 (4.00)	1.54	5.12		
Methionine‡	0.43 (2.14)	0.56 (2.49)	0.47 (1.99)	0.37 (1.69)	0.76 (2.61)	0.80 (2.42)	0.70 (2.26)	0.55 (1.82)	0.80	2.68		
Cysteine	0.27 (1.35)	0.28 (1.24)	0.36 (1.67)	0.27 (1.35)	0.36 (1.24)	0.34 (1.12)	0.45 (1.45)	0.37 (1.22)	–	–		
Phenylalanine§	0.72 (3.58)	0.76 (3.40)	0.76 (3.22)	0.67 (3.06)	1.09 (3.75)	1.04 (3.14)	1.12 (3.31)	0.94 (2.85)	1.13	3.75		
Threonine	0.76 (3.78)	0.85 (3.78)	0.73 (3.09)	0.65 (2.97)	1.13 (3.88)	1.10 (3.34)	1.04 (3.08)	0.90 (2.73)	1.12	3.75		
Valine	0.84 (4.18)	1.00 (4.44)	0.92 (3.90)	0.82 (3.74)	1.28 (4.40)	1.37 (3.99)	1.29 (3.82)	1.11 (3.36)	0.84	2.80		
Asp	1.74	1.95	1.72	1.61	2.53	2.63	2.41	2.17	–	–		
Glu	2.86	3.29	3.31	3.06	4.08	4.32	4.34	4.24	–	–		
Ser	0.77	0.83	0.79	0.68	1.10	1.07	1.06	0.94	–	–		
Gly	1.09	1.19	1.04	0.91	1.74	1.57	1.53	1.31	–	–		
Ala	0.97	1.14	0.92	0.84	1.56	1.53	1.30	1.16	–	–		

*Figures in parentheses refer to dietary amino acids expressed as a percentage of protein.

†O, onoma; A, anchovy; F-R SFC, fibre-reduced sunflower cake; H-F SFC, high-fibre sunflower cake. 20% and 30% refer to dietary protein levels.

‡Cysteine level should be at least 0.15% of the diet (DM basis) or 0.54% of dietary protein.

§Tyrosine level in the diets should be 0.5% of diet (DM basis) or 1.79% of protein.

The apparent digestibility coefficients for protein (ADC-P) are listed in Table 5. Anchovy and omena fishmeals had an ADC-P of 90%. The fibre-reduced and high-fibre sunflower cakes had ADC-P values of 89% and 86%, respectively, which were not significantly different. Wheat bran had an apparent protein digestibility coefficient of 75%, which was significantly lower ($P < 0.05$) than the values found for the other ingredients. Apparent digestibility coefficients for energy (ADC-E) were higher in the animal protein sources than in the plant protein sources. Anchovy fishmeal had an ADC-E of 86%, whereas omena fishmeal had an ADC-E of 78%, which were not significantly different. ADC-E values

in the fibre-reduced and high-fibre sunflower cakes were 42% and 30%, respectively, whereas the digestible energy contents were 2203 kcal kg⁻¹ DM and 1401 kcal kg⁻¹ DM respectively. Differences in ADC-E were not significant, but the differences were significant when expressed as DE concentration ($P < 0.01\%$).

The trend in apparent organic matter digestibility (ADC-OM) was similar to that observed for energy digestibility. The fishmeals had the highest organic matter digestibility. ADC-OM was higher in the fibre-reduced cake than in the high-fibre cake, but the differences were not significant.

Table 5 Apparent digestibility coefficients (ADCs) and digestible energy values for the fibre-reduced and high-fibre sunflower cakes, omena fishmeal, anchovy fishmeal and wheat bran

Protein ADC [†] (%)	Energy ADC [†] (%)	DE [*] kcal kg ⁻¹	Organic matter ADC [†] (%)	
Fibre-reduced SFC [‡]	88.60 ^{a§}	42.10 ^b	2203 ^b	37.20 ^b
High-fibre cake	85.60 ^a	29.70 ^b	1401 ^c	30.80 ^b
Omena fishmeal	89.70 ^a	78.20 ^a	3624 ^a	74.70 ^a
Anchovy fishmeal	90.00 ^a	86.00 ^a	4003 ^a	76.50 ^a
Wheat bran	75.20 ^b	37.10 ^b	1787 ^{bc}	30.30 ^b
SEM	1.90	2.65	132.7	2.57

*DE, digestible energy.

[†]ADC, apparent digestibility coefficient.

[‡]SFC, sunflower cake.

[§]Means ($n = 3$) within a column with a common superscript are not significantly different ($P > 0.05$).

Table 6 Effect of protein level on fish performance

Protein level	Low protein	High protein	SEM
Final weight (g per fish)*	51.40 ^{b†}	57.10 ^a	0.96
Weight gain (g per fish)	35.00 ^b	40.40 ^a	0.90
Specific growth rate (% day ⁻¹)	1.47 ^b	1.58 ^a	0.03
Feed intake (g per fish)	76.70 ^a	75.30 ^a	0.47
FCR [‡]	2.20 ^a	1.87 ^b	0.04
PER [§]	2.16 ^a	1.69 ^b	0.02
PPV [¶]	39.44 ^a	32.21 ^b	0.36

*Values are means of 12 replicates except the final fish weights where individual fish weights were used ($n = 300$).

[†]Means with a different superscript for each factor in a row are significantly different ($P < 0.05$).

[‡]FCR, feed conversion ratio (feed intake/weight gain).

[§]PER, protein efficiency ratio.

[¶]PPV, productive protein value.

Table 7 Effect of source of protein on fish performance

Diets	Omena fishmeal	Anchovy fishmeal	Fibre-reduced sunfl. cake	High-fibre sunfl. cake	SEM
Final weight (g per fish)*	52.40 ^{b2}	57.70 ^a	54.90 ^{ab}	52.00 ^b	1.34
Weight gain (g per fish) [†]	35.92 ^{ab}	40.86 ^a	38.73 ^{ab}	35.39 ^b	1.27
Specific growth (% day ⁻¹) [†]	1.48	1.59	1.57	1.47	0.04
Feed consumption (g per fish) [†]	77.10	75.90	76.10	74.90	0.66
FCR	2.17	1.87	1.98	2.12	0.07
PER	2.01	1.98	1.86	1.84	0.06
PPV	38.90 ^a	37.00 ^{ab}	35.14 ^{ab}	32.30 ^b	1.27

*Values are means of six replicates except the final fish weights where individual fish weights were used ($n = 150$).

[†]Means that do not have a superscript or share a common superscript letter for each factor within a row are not significantly different ($P > 0.05$).

Fish growth and feed and protein utilization

The effects of dietary protein level and protein source on absolute weights, weight gains, growth rates and feed and protein utilization of the fish after 78 days of feeding on the various diets are shown in Tables 6 and 7. At the start of the study, fish in all the groups had similar mean weights ($P > 0.05$). After 78 days, the fish fed the high-protein diets had higher growth rates ($P < 0.05$) than those fed the low-protein diets (Table 6). The interaction between protein level and source was not significant for any of the performance parameters. The growth rates of the fish increased in direct relation to the dietary protein level. Feed intake was not significantly affected by dietary protein level, but feed conversion ratio was better for fish fed the high-protein diets compared with the low-protein diets. Protein utilization (PER and PPV) decreased at the higher level of protein intake.

Dietary protein source had little influence on fish performance (Table 7), except in tilapia ingesting the diets containing the high-fibre sunflower cake, which had reduced weight gain and protein utilization relative to those fed the diets based on anchovy fish meal and omena fish meal respectively.

Discussion

The results of this study are in agreement with the findings of other authors despite the fact that different methodologies were used in the various studies. For example, with respect to fishmeal, Watanabe, Takeuchi, Satoh, & Kiron (1996) observed an apparent protein digestibility of 92% for white fishmeal and a local fishmeal fed to *O. niloticus* (L.). Further, Hanley (1987) reported an ADC-P value of 87% for fishmeal made from different species of fish. Watanabe *et al.* (1996) used digestibility chambers (described by Cho & Slinger 1979) for the collection of faeces, whereas Hanley (1987) collected faeces by intestinal dissection. There is limited information on the digestibility of protein in sunflower cake by tilapia. Sintayehu, Mathies, Mayer, Burgdorff, Rosenow & Gunther (1996) determined the protein digestibility of sunflower cake that had a crude fibre content of 29.4% (AD basis) using HCl-insoluble ash as the indigestible marker. Apparent digestibility of protein in that study was 89.8%, which was not appreciably different from the values of 86% and

89% observed in this study for the high-fibre and fibre-reduced cakes respectively.

Commercial binders are expensive, and wheat and wheat products are often used to increase pellet stability in water. Wheat bran is an inexpensive product that could be used as a binder in pellets. Information on the digestibility of protein in wheat bran for tilapia species is limited. Popma (1982) determined that the apparent protein digestibility of wheat bran in tilapia was 71%, a value close to that of 75% observed in the present study. It is not clear why the digestibility of protein in wheat bran was lower than that of the other ingredients assessed in this study, particularly the high-fibre and fibre-reduced sunflower cakes. Popma (1982) attributed the low digestibility of wheat bran to the feeding habits of tilapia, pointing out that tilapia repeatedly pick up and expel pelleted feeds before swallowing. In this process, the pellet disintegrates, which may lead to selective feeding on individual components of the diet. That author observed selective feeding in coarsely textured and less palatable diets (coffee pulp, wheat bran and alfalfa meal). In contrast to the above argument, the digestibility of protein in the high-fibre sunflower cake used in the current study was not significantly different from that of fishmeal, despite being coarsely textured. Furthermore, in the study by Popma (1982), ground raw corn, which had the same texture as wheat bran, had an apparent protein digestibility of 84%, which was not significantly different from that of the fishmeal used in that study. This may indicate that there were other factors that affected the digestibility of protein in the wheat bran, which need further investigation.

The ADC-E values observed for the two fishmeals are comparable with those reported by Hanley (1987) and Anderson *et al.* (1991). The fishmeal used in the study by Hanley (1987) was made from different species of fish, whereas that used by Anderson *et al.* (1991) was not defined. ADC-E of fishmeal is affected by many factors, including the source, composition and freshness of the fish and the processing temperatures involved in the production of the meal. Fish lipids are high in polyunsaturated fatty acids, which are susceptible to oxidation during processing. High temperatures also cause lipid peroxidation resulting in reduced digestibility (Davadasan, Nair & Antony 1985).

Despite the reduction in fibre content, the fibre-reduced sunflower cake had a low ADC-E value compared with the fishmeals. Some authors have

reported low digestibility of carbohydrates in sunflower cake. In rainbow trout, Sanz, Morales, De La Higuera & Cardenete (1994) found a digestibility of 40% for carbohydrates compared with 50% for soybean meal carbohydrates. Bendi & Spandorf (1953) also observed a low digestibility (26%) of carbohydrates in sunflower cake by carp.

Fish fed diets based on the high-fibre cake gained less weight ($P < 0.05$) over the whole experiment than fish receiving the diets based on anchovy fishmeal. They also tended to have lower feed intake and a higher feed:gain ratio compared with those fed on the other three diets, but the differences were not significant. Tilapia, like other fish, consume organoleptically acceptable diets in an attempt to satisfy their energy demands. The DE concentration in all the diets was almost similar, which may explain the similarity in feed intake. Diets based on the high-fibre cake had a slightly lower DE concentration compared with the other diets. Despite this, the fish fed on these diets did not increase their feed intakes to compensate for the lower dietary DE content. Residual hulls in the high-fibre diets (H-FSC 20 and H-FSC 30) may have hindered this compensatory increase in feed intake.

The results of this study indicate that protein from sunflower cake, regardless of its fibre content, is well digested by *O. niloticus* at a level that is not markedly different from that of high-quality fishmeal. Similarly, the digestibility of protein in the locally produced omena fishmeal was equal to that of the high-quality anchovy fishmeal. Reducing the fibre content in sunflower cake increased the digestibility of nutrients and energy, thereby increasing its feeding value. The greatest effect of fibre reduction was observed in the digestibility of energy, with the value increasing from 30% to 42%. Compared with fishmeal and soybean meal, sunflower cake is inexpensive, and the digestibility values suggest that the fibre-reduced sunflower cake could be used at high levels of replacement in tilapia diets with little need for adjustment in dietary crude protein level. Additional lipid may be necessary to adjust the DE concentrations, but increasing voluntary feed intake using appetite enhancers could at least partially counteract the dilution in dietary DE. The results also suggest that it may be possible to use omena fishmeal, which is locally available, to replace the imported expensive fishmeals in diets for tilapia and perhaps other fish species.

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