Journal of Fisheries International 3 (4): 98-104, 2008
ISSN: 1817-3381

Dietary Nitrogen Utilization in African Catfish, *Clarias gariepinus* Fed Oil Seed Meal Based Diets under Sub-Optimal Growth Conditions Consistent with a Restricted Feeding Regime

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Abstract: A 42 days feeding trial was undertaken to assess the modulation of rapeseed and cottonseed meals on dietary nitrogen utilization in the African catfish, *Clarias gariepinus* fed a reduced feed schedule simulating the practice of maintaining fish stock prior to intensive production on higher feeding regimes. Ten iso-nitrogenous (36% crude protein, N×6.25) and isocaloric diets were formulated. Two diets served as a reference formulation; one an all fishmeal based diet and the other a soybean meal/fishmeal combination. This latter protein combination was effectively replaced by 15, 30, 45 and 60%, respectively of each test ingredient. It was concluded that between 15 and 30% of the diet could be effectively replaced with rapeseed and cottonseed meals, respectively without detriment to Apparent Net Nitrogen Utilization (ANNU) and in respect of several other parameters i.e., Protein Efficiency Ratio (PER), Feed Conversion Ratio (FCR) and carcass composition. These were found to be in accordance with other reported data in the literature for African catfish. However, it was found that higher inclusion of these ingredients resulted in inferior ANNU. These ranged from 37.05-31.04% for rapeseed meal and from 32.59-17.72% for cottonseed meal. Findings are reported in the context of formulating low cost feeds for this species under holding conditions without detriment to their nutritional status.

Key words: Cottonseed and rapeseed meals, African catfish, nitrogen deposition and retention, low feeding regime, sub-optimal growth

INTRODUCTION

Plant proteins have been extensively investigated for use in fish feed formulations for aquaculture (Gatlin *et al*., 2007). These have included various pulses and lupins in carnivorous fish such as rainbow trout *Oncorhynchus mykiss* (Glencross *et al*., 2004, 2007), Atlantic salmon *Salmo salar* (Carter and Hauler, 2000; Refstie *et al*., 2006) and European sea bass *Dicentrarchus labrax* (Gouveia and Davies, 2000). However, soybean meal and related by-products have been more widely used in fish diets (Fagbenro and Davies, 2001; Drew *et al*., 2007; Gatlin *et al*., 2007; Goda *et al*., 2007) and are of prime importance in tropical omnivorous fish feeds. El-Sayed (1999) reviewed the alternative protein sources available for tilapia, *Oreochromis* sp. and specified the major plant proteins of interest. Since, African catfish *Clarias gariepinus* are now reared outside the African continent and are a highly valued species it is also, necessary to evaluate different protein ingredients for this species.

Rapeseed meal and cottonseed meals are also valued commodities that have attracted interest for use in fish feed formulations. The term rapeseed covers numerous species of *Brassica* sp. which are grown primarily for their oil content in Europe, North America, Southeast Asia and Africa. The potential of rapeseed meal as a protein source in fish diets is limited by the presence of a number of anti-nutritional factors (Drew *et al*., 2007; Tripathi and Mishra, 2007). These include protease inhibitors, sinapine, phytic acid, tannins and particularly glucosinolates (Francis *et al*., 2001; Thiessen *et al*., 2003).

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Several workers have undertaken research investigations to evaluate the nutritional potential of *Brassica* sp. derived products (e.g., mustard oil cake and rapeseed meal) in tropical fish with variable success (Mohanta *et al*., 2007). This was also due to the presence of glucosinolates and a possible adaptation to goitrogen activity.

There are similar constraints with regard to the use of cottonseed derived meals for fish species (Li and Robinson, 2006). Barros *et al*. (2002) reported that cottonseed meal can replace up to 50% of soybean meal in diets for channel catfish, *Ictalurus punctatus*, with lysine supplementation however, total replacement of soybean meal by cottonseed meal became inhibited growth performance. The presence of free gossypol above 0.1% of the diet is inhibitory to both feed utilisation and growth. Mbahinzireki *et al*. (2001) determined that cottonseed meal could effectively replace up to 50% of fishmeal protein in diets for juvenile tilapia. Gossypol in the test diets ranged from 0.11-0.44% of the diet and resulted in proportional levels in the liver.

Most investigations concerning the African catfish have focused on primarily using established oilseeds such as soybean meal and pulses as protein sources (Fagbenro, 1999; Fagbenro and Davies, 2001), to support intensive growth of this species. Both rapeseed and cottonseed meals are also important ingredients for the formulation of low cost diets for tropical fish species and these by-products also require evaluation for African catfish under varying practical conditions.

In aquaculture practice, restricted feeding regimes are often employed for maintaining or holding fish prior to intensive grow-out. Such conditions commonly include a reduced feeding level above maintenance requirements for extended durations whilst still allowing moderate growth to occur. In fact, the importance assessing the maintenance ration and energy requirements for tilapia was advocated by Richter *et al*. (2002), for the prime purpose of storing tilapia prior to the grow-out phase. In fact, Ali and Jauncey (2004) evaluated various mixed feeding schedules with respect to compensatory growth and composition in African catfish with periods of feeding to maintenance (1% bw day^{-1}) using soybean meal and fishmeal based diets without detriment to growth potential and protein utilization.

It would therefore, be important to formulate low cost diets that can support fish development whilst also promoting efficient protein utilization and particularly tissue retention under such a phase of reduced growth. However, there is limited information on the utilisation of alternative protein sources and their efficacy under sub-optimal growth for fish and especially tropical species such as African catfish. Consequently, a short term nutrition trial was undertaken to assess protein (nitrogen) retention for the African catfish using rapeseed and cottonseed meals as cost effective ingredients in diets for restricted feeding regimes over a defined period.

MATERIALS AND METHODS

Experimental fish and procedure: This trial was performed with juvenile African catfish *C. gariepinus* of initial mean weight of 37 g juvenile fish were obtained from a defined Plymouth University lineage. The trial was conducted in triplicate using a recirculation system consisting of (25 L) polyethylene tanks. Replicate tanks were supplied with a flow rate of 4 L min^{-1} of re-changed water. Temperature was maintained at 27.5±1°C throughout the 42 days trial under a photoperiod regime of 12 h light and 12 h dark. Water parameters i.e., NH_3, NO_2^- and NO_3^- were also maintained at a suitable level for the species. The catfish were weighed individually at the start and termination of the experiment and bulk weighed weekly for the ration level to be adjusted accordingly.

Experimental diets and feeding regime: Ten experimental test diets were designed according to the composition displayed in Table 1a and b. Each diet was assigned a code: Fishmeal control diet-Fc, the soybean meal/fishmeal control diet (S/Fc) the diets containing rapeseed meal were termed diets Ra-Rd and those containing cottonseed meal Ca-Cd, respectively.

The fishmeal control diet (Fc) was formulated to meet the known nutrient requirements for the African catfish and to comply with standard defined requirements for tropical fish. The soybean meal/fishmeal control diet (S/Fc) was produced on a 1:1 ratio with respect to crude protein. This diet served as an additional control using a standard soybean meal as a plant reference source. The eight remaining diets containing cottonseed and rapeseed were included at 15, 30, 45 and 60% replacement levels of the fishmeal protein component.

All 10 diets were designed to be iso-caloric and iso-nitrogenous in terms of gross energy and protein.

The rapeseed meal (International Feed Number: 5-03-871) used was a typical de-hulled, heat treated, solvent extracted European variety with a crude protein content of 34.7% and a lipid level of 2.8%. The total glucosinolate (GLS) content was determined to be 51 μ Mg^{-1} and a euricic acid not exceeding 2% the oil content. These were characteristic of a double low rapeseed meal product.

The cottonseed meal was of a Chinese source (International Feed Number: 5-01-619), obtained by grinding the residual press-cake after removal of most of the oil from de-hulled pre-cooked cottonseed by a solvent extraction process (47% crude protein; 0.5% crude lipid; 12.5% crude fibre and a free gossypol of <0.04%, Torre

Feeds Ltd., Exmouth, Devon, UK). The meals were further through a 300 μ-mesh sieve prior to incorporation into the dry ingredients.

The basal protein source for the diets originated from a brown, herring fishmeal (66% crude protein) obtained from W. Carne and Sons; Crediton Feed Mill, Cornwall, UK.

Two sources of supplementary lipids were used of marine origin and one of vegetable origin. The marine oil was in the form of pure cod liver oil and the vegetable source was pure corn oil. The ratio was adjusted according to the lipid contribution from the major ingredients. The carbohydrate source used in all diets was in the form of a feed grade wheat meal. The inclusions for each ingredient in diets together with nutrient analysis are displayed in (Table 1a and b). All diets were prepared as described previously by Gouveia and Davies (2000).

Chemical analysis: At the end of the trial 6 fish from each tank were randomly selected and killed by lethal anaesthetisation, frozen at -20°C and later processed for carcass composition as described below. Proximate analysis on feedstuffs, diet and fish were performed according to the methods of described by Gouveia and Davies (2000). Dry matter was determined after drying at 104°C until constant weight. Ash content was measured by incineration in a muffle furnace at 600°C for a period of 12 h. Crude protein (N×6.25) was performed by the automated Kjeldhal method after acid digestion using the Gerhardt system. Lipid extractions were undertaken by a refinement of the original version of the Folch method. Energy content of diets is presented as calculated values based on the Philips physiological fuel values for each nutrient component.

Glucosinates containing sinigrin as a standard were isolated on a DEAD sephadex ion exchange column and desulphated using a purified sulphatase preparation. The resulting solution of desuphoglucosinates was separated and measured by reverse phase High Performance Liquid Chromatography (HPLC).

Gossypol levels in cottonseed meal was determined according to the extraction protocol and subsequent HPLC detection by the methods of Kim and Calhoun (1995) and modified by Mbahinzireki *et al.* (2001).

Statistical application: Evaluation of the growth performance and nutritional parameters were assessed by one-way analysis of variance using the statgraphics 7 for Windows software package ($p>0.05$). Significant differences among means were determined by the subsequent use of Duncan's multiple ad-hoc range test. Tank average values were considered as units of observation. Regression analysis was performed with Minitab 13 for Windows software package.

Table 1a: Composition of the controls and rapeseed experimental diets (dry weight)

	Diets (g kg^{-1} dry weight)					
Ingredients	Fc	S/Fc	Ra 15%	Rb 30%	Rc 45%	Rd 60%
Norwegian fishmeal	539	270	458	377	297	216
Soybean meal	-	380	-	-	-	-
Rapeseed meal	-	-	128	256	384	512
Cod liver oil	53	17	10	17	24	31
Maize oil		46	46	43	39	36
Vitamin and mineral premix[1]	40	40	40	40	40	40
Vitamin C[2]	1	1	1	1	1	1
Wheat flour	367	246	317	266	215	164
Protonal[3]	10	10	10	10	10	10
Proximate analysis						
Moisture (%)	7.82	3.99	6.82	6.35	7.21	8.23
Crude protein (DM %)	38.91	37.59	38.8	37.14	37.04	36.29
Crude lipid (DM%)	13.52	13.90	15.67	15.15	15.42	13.96
Ash (DM%)	6.5	5.41	5.41	6.27	6.23	6.73

Table 1b: Composition of the controls and cottonseed experimental diets (dry weight)

	Diets (g kg^{-1} dry weight)					
Ingredients	Fc	S/Fc	Ca 15%	Cb 30%	Cc 45%	Cd 60%
Norwegian fishmeal	539	270	458	377	297	216
Soybean meal	-	380	-	-	-	-
Cottonseed meal	-	-	152	305	457	609
Cod liver oil	53	17	10	17	24	31
Maize oil		46	47	45	42	40
Vitamin and mineral premix[1]	40	40	40	40	40	40
Vitamin C[2]	1	1	1	1	1	1
Wheat flour	367	296	292	215	139	63
Protonal[3]	10	10	10	10	10	10
Proximate analysis						
Moisture (%)	7.82	3.99	7.04	7.8	10.22	9.35
Crude protein (DM%)	38.91	37.59	40	38.94	39.9	39.62
Crude lipid (DM%)	13.52	13.90	14.08	14.02	13.69	13.53
Ash (DM%)	6.5	5.41	6.49	6.77	7.02	6.95

[1]Salmonid production formulation; Trouw Aquaculture UK Ltd (exceeding known requirements for tropical freshwater fish, NRC, 1993); [2]Ascorbyl phosphate (Rovimix); Rôche Animal Nutrition; [3]Binder

RESULTS

Data obtained for Apparent Net Nitrogen Utilisation (ANNU) were consistent with a reduced utilisation of dietary protein for both test ingredients at higher inclusion levels (Table 2a and b). The regression analysis of ANNU and inclusion level for each ingredient (Fig. 1 and 2) clearly show negative relationship between Nitrogen utilization as a consequence of substitution.

African catfish fed diets Ra-Rc resulted in ANNU values that were higher than the fishmeal control group (35.08%) but inferior to the S/Fc group (45.68%). Catfish fed diet Rd gave an ANNU value (31.04%) that was appreciably lower than values obtained by catfish fed each of the other treatments.

Fish fed the cottonseed based diets produced ANNU values that followed a similar pattern, with a

Table 2a: Growth performance and diet utilization by African catfish fed the controls and the rapeseed experimental diets[1]

	Controls		Protein replacement from rapeseed (%)				
Ingredients	Fc	S/Fc	Ra 15%	Rb 30%	Rc 45%	Rd 60%	±SEM
Initial mean weight (g)	36.78	38.63	35.54	37.95	37.52	37.23	0.43
Final mean weight (g)	73.32^{ab}	79.76^{a}	68.37^{bc}	67.08_{bc}	64.87^{bc}	61.61^{c}	2.64
Weight gain (%)[2]	99.35	106.47	92.37	76.76	72.89	65.48	-
Mean weight gain (mg/fish/day)[3]	730.86	781.45	656.50^{6}	582.56	551.80	487.60	45.61
Mean food intake (mg/fish/day)	773.51	802.25	738.11	742.80	732.63	727.60	11.87
Specific growth rate (SGR%)[4]	1.64^{a}	1.73^{a}	1.56^{b}	1.36_{b}	1.30^{c}	1.20^{d}	0.09
Feed conversion ratio (FCR)[5]	1.06^{a}	1.03^{a}	1.12_{b}	1.28^{c}	1.33_{c}	1.49^{d}	0.07
Nitrogen intake (mg/fish/day)[6]	45.15	47.10	41.13	41.37	41.58	39.63	0.31
Nitrogen deposition (mg/fish/day)[7]	15.84	21.75	15.24	14.81	14.64	12.30	0.43
Protein efficiency ratio (PER)[8]	2.43^{b}	2.59^{a}	2.29^{b}	2.11^{c}	2.03_{d}	1.85^{e}	0.11
Apparent net nitrogen utilisation (ANNU%)[9]	35.08	45.68	37.05	35.80	35.21	31.04	-

Table 2b: Growth performance and diet utilization by African catfish fed the controls and the cottonseed experimental diets[1]

	Controls		Protein replacement from rapeseed (%)				
Ingredients	Fc	S/Fc	Ca 15%	Cb 30%	Cc 45%	Cd 60%	±SEM
Mean initial weight (g)	36.78	38.63	36.87	36.08	38.61	36.14	0.47
Mean final weight (g)	73.32^{ab}	79.76^{a}	70.53^{ab}	72.90^{ab}	64.55^{b}	53.54^{c}	3.69
Weight gain (%)[2]	99.35	106.47	91.29	102.05	67.18	48.13	-
Mean weight gain (mg/fish/day)[3]	730.86	802.25	744.69	761.95	734.71	669.13	17.80
Specific Growth Rate (SGR%)[4]	1.64^{ab}	1.73^{a}	1.54^{b}	1.68^{a}	1.22^{c}	0.93^{d}	0.13
Mean food intake (mg/fish/day)	773.51	781.45	653.01	736.36	503.63	347.97	70.89
Feed conversion ratio (FCR)[5]	1.06^{a}	1.03^{a}	1.14^{b}	1.05^{a}	1.46^{c}	1.92^{d}	0.14
Nitrogen intake (mg/fish/day)[6]	45.15	47.01	47.04	44.52	46.29	39.78	0.39
Nitrogen deposition (mg/fish/day)[7]	15.84	21.75	15.33	16.74	10.56	07.05	0.70
Protein Efficiency Ratio (PER)[8]	2.43^{b}	2.59^{a}	2.19^{c}	2.48^{b}	1.72^{d}	1.31^{e}	0.21
Apparent Net Nitrogen Utilisation (ANNU)[9]	35.08	45.68	32.59	36.78	22.81	17.72	-

[1]In the same line, values with different superscript letters are significantly different ($p<0.05$); [2]Weight gain (%): final body weight- initial body weight/initial body weight×100; [3]Mean daily weight gain (mg/fish/day); final body weight-initial body weight/days; [4]Specific growth rate (%): ln final body weight- ln initial body weight×100/(days); [5]Feed conversion ratio: feed intake DM/live weight gain; [6]Daily nitrogen intake (mg/fish/day): protein intake/×6.25; [7]Daily nitrogen deposition (mg/fish/day): weight gain/nitrogen intake; [8]Protein efficiency ratio: weight gain/protein intake; [9]Apparent net nitrogen utilisation (ANNU%): (nitrogen deposition/nitrogen intake)×100

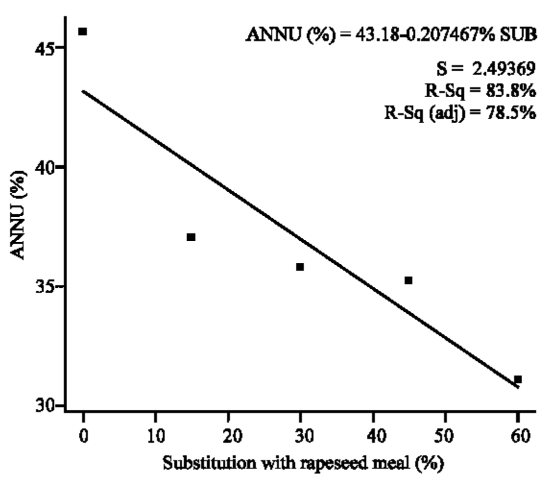

Fig. 1: Regression line of Apparent Net Nitrogen Utilization (ANNU) against percentage substitution of rapeseed meal

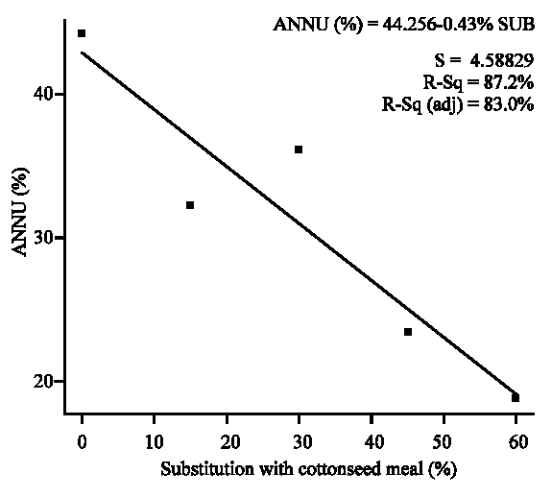

Fig. 2: Regression line of Apparent Net Nitrogen Utilization (ANNU) against percentage substitution of cottonseed meal

marked reduction in protein utilisation above 30% dietary protein inclusion for catfish fed diets Cc and Cd (i.e., 22.81 and 17.72%, respectively). Furthermore, all values being lower than that determined for the S/Fc catfish group.

The feed utilisation and growth response parameters determined for the catfish fed the experimental diets are also shown in Table 2a and b. The Specific Growth Rate (SGR) for S/Fc was 1.73 compared to 1.56 for diet Ra (15% rapeseed protein) and 1.20 for diet Rd (60% rapeseed

Table 3a: Proximate composition of African catfish fed the rapeseed experimental diets[1]

Parameter	Fc	S/Fc	Ra	Rb	Rc	Rd	±SEM
Water content (%)	73.86[a]	72.94[ab]	72.63[ab]	72.49[b]	73.39[ab]	73.02[ab]	0.21
Crude protein (%)	14.75[c]	16.35[a]	15.22[bc]	16.40[a]	16.20[ab]	15.72[abc]	0.27
Crude lipid (%)	6.18[b]	6.22[b]	7.28[a]	7.41[a]	5.99[b]	7.47[a]	0.29
Ash (%)	3.87[a]	3.01[c]	3.70[ab]	3.52[ab]	3.38[bc]	3.34[bc]	0.12

Table 3b: Proximate composition of African catfish fed the cottonseed experimental diets[1]

Parameter	Fc	S/Fc	Ca	Cb	Cc	Cd	±SM
Water content (%)	73.86[abc]	72.94[c]	74.26[ab]	73.48[bc]	74.64[a]	74.54[a]	0.27
Crude protein (%)	14.75[b]	16.35[a]	14.60[b]	15.16[b]	14.43[b]	14.52[b]	0.29
Crude lipid (%)	6.18[c]	6.22[c]	6.29[c]	7.14[a]	6.84[b]	6.39[c]	0.16
Ash (%)	3.87[a]	3.01[c]	3.64[ab]	3.50[ab]	3.44[b]	3.51[ab]	0.11

[1]In the same line, values with different superscript letters are significantly different ($p<0.05$)

protein) ($p>0.05$). The SGR values calculated for catfish fed the cottonseed meal produced an SGR of 1.68 (at 30% cottonseed protein) and this decreased significantly to 1.22 for diet Cc (45% cottonseed protein) and 0.93 for diet Cd (60% cottonseed protein), respectively ($p>0.05$). Both the Feed Conversion Ratio (FCR) and the Protein Efficiency Ratio (PER) reflected the reduction in ANNU and SGR data and proved significantly ($p>0.05$) inferior for the high inclusion levels for each ingredient. African catfish fed the 2 control diets showed superior FCR's in general (Fc 1.06 and S/Fc 1.03) compared to the groups receiving the test protein source. Throughout the trial the fish remained healthy and over the whole period there was only a random 2% mortality rate.

Carcass composition of all fish taken at the termination of the trials is displayed in Table 3a and b. The protein content of the fish was found to be slightly higher in fish fed diets S/Fc and Ra-Rd compared to Fc and Ca-Cd. There was also variation within each set of fish but this followed no obvious pattern. The percentage lipid in the carcass resulted in the highest value found in fish fed diet Rd (7.47%) and the lowest in fish fed diet Rc (5.99%).

DISCUSSION

It was shown that a replacement of fishmeal protein with rapeseed meal was detrimental to protein utilization above 15% for African catfish fed 2% bw day^{-1}.

Davies *et al.* (1990), working with tilapia *O. mossambicus* also found that rapeseed meal could be incorporated into the diet at 15% with inclusions above this level leading to reduced protein utilization. Webster *et al.* (1997) assessed canola meal diets for juvenile channel catfish and deduced that it could be successfully included at 36% of the total diet without affects on fish growth performance.

For African catfish, there was a marked decline in the ANNU values, which correlated with the incremental inclusion of rapeseed meal. The Nitrogen Retention Efficiency (NRE) values calculated in this research were also similar to those in other investigations on African catfish when fishmeal was replaced with soybean meal protein. Goda *et al.* (2007) obtained 25.39% dietary NRE for African catfish fed fishmeal as the sole protein source compared to 25.41% when African catfish were fed a complete soybean meal based diet. Interestingly, the soybean meal/fishmeal reference diet used in our study resulted in a superior protein retention compared to fishmeal alone. Similar findings have also been reported by Webster *et al.* (1997) in studies designed to compare the potential of canola meal as soybean meal substitutes for channel catfish. Again, canola meal inclusion of both 12 and 48%, respectively caused a reduction of the ANNU from 32% for a soybean meal/fishmeal protein combination (50.75:8.00) to 29 for 12% canola meal inclusion and a further reduction to 23 at 48% inclusion. These trends are in support of our present findings with the African catfish.

African catfish fed the cottonseed diets in our investigation did not show any appreciable changes in ANNU up to a cottonseed meal 30% inclusion level. However, there was a more marked decrease in feed utilisation above 45% inclusion compared to only a gradual reduction for rapeseed meal fed fish. Likewise, Toko *et al.* (2008) assessed cottonseed meal diets for juvenile African catfish and reported that it could be successfully included at 30% of the total diet without affects on fish growth performance. In a study by Toko *et al.* (2007), 30% of dietary cottonseed meal supplementation produced equivalent growth and feed utilization in vundu catfish, *Heterobranchus longifilis*, when compared to soybean meal and fishmeal based diets.

This was inferred from the negative regression with the ANNU values obtained in this study. The potential of cottonseed to replace fishmeal protein was viable up to a level of 30% before a severe reduction in ANNU was evident. The fish fed diets containing higher inclusion levels showed no significant difference to the soybean meal/fishmeal control unlike the rapeseed diets. Values for NRE were of similar magnitude to those reported for

African catfish by Ali and Jauncey (2004), for the soybean meal and fishmeal meal diets at 45%. These latter workers obtained values of over 50% for the rapid phase of growth following maintenance feeding for varying periods. Interestingly, the soybean meal/fishmeal reference diet used in our study resulted in a superior protein retention compared to fishmeal alone (35%). Growth and nitrogen utilisation of fish are influenced by feeding level. For example, Hassan and Jafri (1994) declared that between a feeding rate 3 and 4%, a larger ratio of dietary nutrients was utilised by African catfish for its growth and protein utilisation. These workers suggested that growth and NRE of catfish fed the lowest ration level (1.0% bw day^{-1}) at 30°C appeared to be closer to maintenance levels. Toko *et al.* (2008) indicated that the lower nitrogen retention in African catfish was obtained with a diet containing up to 60% cottonseed meal compared to a fishmeal based control diet under a normal feeding regime similar to that of Hogendoorn *et al.* (1983) for the same species, *Clarias gariepinus*.

The results of the present investigation could be explained by a favourable balance of amino acids in the control diets and those diets containing a low inclusion level of plant protein. As the replacement of soybean meal or fishmeal increases, so the balance of the amino acid profile will become unfavourable for the net retention and accretion of the essential amino acids. In rapeseed the first limiting amino acid is lysine and in cottonseed both lysine and methionine are the first limiting amino acids (Li and Robinson, 2006). In the current study, the decreasing nitrogen retention by African catfish fed the highest levels of cottonseed protein could also be due to a reduced availability of lysine.

More research is needed to establish the protein and preferably the individual essential amino acid availability and retention for both cottonseed and rapeseed meals for this species at optimum feeding levels for maximum growth over a longer period. Experiments should also address the metabolic (branchial) losses of nitrogen (NH_3) resulting from lower nitrogen retention of diets high in rapeseed and cottonseed meals for African catfish over a range of feeding levels from maintenance to optimum growth conditions. Investigations should also be undertaken to evaluate the compensatory growth of catfish after a period of restrictive feeding of lower specification diets.

Finally, this study has shown that it is possible to include lower cost oilseed meal proteins in diets for juvenile African catfish without compromising their nitrogen equilibrium and nutritional status under sub-optimum growth conditions. This is of physiological significance with regard to their subsequent intensive grow-out stage applying higher feeding rates to achieve their full growth capacity.

ACKNOWLEDGMENT

The authors appreciate the help of Stuart Maudling for assistance with statistical evaluation of data and Alex Wan for editorial support.

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