Partial replacement of fish meal with either soybean meal, brewers yeast or tomato meal in the diets of African sharptooth catfish *Clarias gariepinus*

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Abstract

As intensively cultured fish usually require high protein feeds, and since feeds are normally the largest variable cost item in commercial production, the profitability of intensive aquaculture is closely related to the world supply and cost of feed protein. Traditionally, fish meal has been the major component of all fish feeds. However, its high cost has necessitated a search for alternative protein sources, especially those that are not suitable for human consumption. This study investigated the partial replacing of fish meal with alternative protein sources (tomato waste, soybean meal, brewers yeast) in iso-nitrogenous diets of *C. gariepinus*. The tomato used consisted of sun-dried pips and skins from ripe tomatoes used in the production of tomato pastes. The soybean consisted of either dehulled, solvent-(hexane) extracted soybean meal (Soy-2) or the same soy meal that had undergone a further extrusion process (Soy-1). The yeast used was a waste product from a local brewery. A final diet consisting of a mixture of the various ingredients was also prepared. Twenty-five catfish (30 to 45 g live mass (LM)) were randomly allocated to 24 500 *ℓ* tanks and four tanks were allocated to each diet. The tanks were then connected to a recirculating system (13 000 *ℓ* total volume) and each had a flow rate of 7 ± 1 $\ell \cdot min^{-1}$. The water temperature was maintained at 25 ± 1°C. The total biomass in each tank was measured weekly and the feed adjusted accordingly. The catfish were fed at 5% of total biomass for the first 4 d and 6% for the last 3 d of the week. The experiment was terminated after a 60 d feeding period. A statistical comparison of the final mean mass showed that all the diets differed significantly from each other (p=0.05), with the exception of the yeast and mixture diet and the yeast and Soy-1 diet. The descending ranking order of the mean final body mass (LM ± standard error, g) of the various diets was as follows: fish meal (284.6 ± 5.2), tomato (261.9 ± 5.3), yeast (222.2 ± 5.7), Soy-1 (220.5 ± 5.2), mix (201.4 ± 5.5), and Soy-2 (115.3 ± 5.5). The relatively strong growth experienced by fish receiving the tomato diet could possibly be caused by the high fish meal content of this diet. The poor growth of the Soy-2 diet is attributed to a high urease activity index (1.73). Soy-1 had an index of 0.07. The growth experienced by catfish fed the various protein sources indicates that *C. gariepinus* are able to utilise alternative protein sources successfully.

Introduction

The rising costs of fish meal (R2.02 in January 1995 to R3.30 in August 1996) and subsequently fish diets, and lack of a proper marketing strategy are the two major factors contributing to the near collapse of the South African sharptooth catfish (*Clarias gariepinus*) industry. The protein requirements of *C. gariepinus* 30 to 40 g fingerlings (Machiels and Henken, 1985; Degani, et al., 1989) are similar to those of *C. isheriensis* (Fagbenro, 1992), namely between 37% and 40% of the feed. In South Africa the major protein source used in fish diets is fish meal. Fish farming therefore competes with other well-established farming practices for fish meal. This competition, coupled with the global decline in marine fish landings (Ratafia, 1995), makes fish meal expensive (August 1996 - R3.30/kg; US$1.00 = SAR4.55).

As commercial feeds for grow-out contain 25 to 45% crude protein, only high-protein content plant foodstuffs such as oilseed residues are used in fish feed. The extent of plant protein usage is also influenced by its availability, cost, acceptability by fish, ease of processing, and nutritive value (Lim and Dominy, 1989). The latter can be enhanced by adding synthetic amino acids. Soybean meal (defatted or fullfat) has been extensively investigated as a partial or full replacement for fish meal in the diets of various fish species. Shiau et al. (1990) found that either defatted or fullfat soybean meal can be used to replace 30% of fish meal protein in a diet for *Oreochromis niloticus X O. aureus* fingerling hybrids when the dietary protein level is low (24%). Gallagher (1994) showed that, in diets for larger hybrid striped bass (*Morone saxatilis X M. chrysops*), up to 75% of the fish meal protein can be replaced with soybean meal protein. The replacement of fish meal with soybean meal in the diets of channel catfish has attracted great interest, e.g. blue catfish *Ictalurus furcatus* (Webster et al., 1992), and the use of alternative protein types in the diets of channel catfish *I. punctatus* has been well reviewed by Lovell (1989) and Wilson (1991). Robinson (1991) studied the influence of cottonseed meal on the growth of *I. punctatus* and found that this proved satisfactory when supplemented with lysine. Other alternative protein sources used with various degrees of success include distillers' grain with solubles in the diets of juvenile *I. punctatus* (Webster et al., 1991), rapeseed meal (Davies et al., 1990), and alfalfa leaf protein concentrates (Olvera-Novoa et al., 1990) in the diets of *O. mossambicus*. Hossain and Jauncey (1989) studied the digestibility of mustard oilcake, linseed and sesame meal for common carp (*Cyprinus carpio*) and found that sesame meal showed the lowest digestibility. Sanz et al. (1994) compared sunflower meal with soybean meal as partial substitutes for fish meal in the diets of rainbow trout (*Oncorhynchus mykiss*) and found that, as with soymeal, sunflower meal could replace up to 40% of fish meal protein.

In the diets of juvenile (3.5 g) African sharptooth catfish

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Clarias gariepinus, Degani et al. (1988) tested fish meal, poultry meal and soybean meal, and found that fish fed the plant protein (soybean) grew significantly slower than those fed the animal protein source.

The present investigation monitored the partial replacement of fish meal with alternative plant proteins, such as extracted and extruded fat-free soybean meal, brewers yeast and tomato waste, and the resulting influence on the growth of *C. gariepinus.* Although tomato waste does not have a high protein value, it is classified as a waste product with no financial value and was therefore included in the diet. The diets were iso-nitrogenous (38% protein) and, where possible, iso-calorific.

The tomato diet gave a good specific growth rate (SGR = 3.23 ± 0.06), second only to that of the control diet (fish meal diet - SGR = 3.43 ± 0.04). The feed cost per kg of catfish mass gain for the tomato was lower (R2.79) than that for fish meal (R4.25). The slow growth experienced with the soybean diets is attributed to high anti-nutritional factors present in the soybean meals (Soy-1 and Soy-2 diets contained respectively 0.07 and 1.73 urease activity indexes). The results of this investigation show that cheaper diets which result in lower but acceptable growth rates for *C. gariepinus* can be compiled. The fish producer will, however, have to decide whether there is an economic justification for using these alternative diets.

Material and methods

Feed ingredients

In this experiment mechanically extracted white fish meal was used as the main protein source in the control diet. In the other diets, it was partially replaced by the different plant products. Cooked maize was used as the major energy source and trimethylcellulose was used as a binder. A commercial clear brown semi-refined fish oil called Marinol W was used as an extra energy source (supplied by Marine Oil Refineries, Dido Valley, Simonstown, South Africa), and a premix of vitamins and minerals was also added (Uys2, Truka, South Africa).

Two soybean products were investigated (Soy-1 and Soy-2) that had been subjected to different factory processes. Both had the same initial factory treatment in which the beans are first cleaned (screened) and then passed through a crusher (fluted two-stage roller), breaking the beans into 6 to 8 particles. The dehulled soybean chips were then conditioned and flaked to soften the bean and coagulate the protein prior to the fat extraction. In this process the moisture content was raised from 10% to 14% by the direct addition of steam, and the soy chips were then heated at 70 to 80°C for 30 min. Thereafter the chips were flaked by being passed through a single set of smooth rollers. These flakes (19% moisture) were defatted by using hexane as the solvent, the fat extraction being done on a carousel rotary unit using a counter-current system. The flakes were exposed to hexane for 1.5 to 2 h at a temperature of 55 to 60°C. The resulting de-fatted flakes have a protein dispersibility index of >65% and are suitable for cattle feed. In our investigation this was the sample known as Soy-2. The Soy-1 sample consisted of defatted soybean flakes (Soy-2) that underwent a further processing by means of an extruder, as follows: the defatted flakes were passed through a Bauermeister grinder until they were 100 to 300 μ in size. These fine flakes were then pre-conditioned for 2 min at 70 to 80°C with the addition of steam (18% moisture) before being passed through a Wenger extruder machine. The duration of the extrusion was 40 to 60 s and the mechanical action raised the temperature to >120°C. The resulting 10 mm chunks were then milled in an Urschel wet mill before being dried on a wenger belt. The moisture content dropped from 14% to 7%. The resulting fine soybean product (Soy-1) was then screened into separate sizes, packed, and stored until needed.

The brewers yeast was of the Carlsberg variety and a waste product from the fermentation process. After being used repeatedly in the manufacturing of beer for seven generations, the yeast is dried on a rotating heated drum (80°C) and discarded. This product is in a fine white powder form and is suitable for animal feeds.

The tomato used is a waste product from commercial farmers, who harvest the ripe tomatoes, mechanically extrude the fruit pulp, and end up with a wet waste residue of skin and seeds. Prior to use in the present investigation, the tomato was sun dried.

Fish and experimental facilities

Six hundred 2.5-month-old golden strain African sharptooth catfish *Clarias gariepinus*, ranging in mass from 30 to 45 g, were allocated to 24 500 *ℓ* tanks (25 fish per tank) which were connnected to a recirculating system (12 000 *ℓ* total volume), each tank having a flow rate of 7 ± 1 $\ell \cdot min^{-1}$. The water temperature was maintained at 25 ± 1°C and the oxygen levels at above 3.4 mg per *ℓ* by means of additional aeration. Water quality parameters were monitored every second day and were well within the limits recommended for *C. gariepinus* (Viveen et al., 1985).

The compositions of the diet components and the final diets fed to the catfish are summarised in Table 1. Fish in four tanks were allocated to each diet.

The total biomass in each tank was measured weekly and the feed adjusted according to this mass. Prior to the commencement of the experiment the catfish were fed a commercial troutdiet (12% moisture, 38% protein, 6% lipid, 4% fibre, Farmix Trout Feed, EPOL, Johannesburg). During the acclimatisation period in the experimental tanks (3 d), the catfish were fed this same trout diet (0.5% of total biomass). After the acclimatisation period, the catfish were fed the experimental diet at 3% of total biomass for 6 d. Thereafter the catfish were fed at 5% of total biomass for the first four days and 6% of total biomass for the last 3 d. This overfeeding, specifically with reference to the last three days of the week, ensured that feed was not restrictive for growth.

The experiment was terminated after a 60 d feeding period. At termination of the experiment, the fish were left for one day to ensure emptying of the stomach contents and then were all individually weighed and examined for abnormalities. Finally, five fish from each tank were pooled and analysed for chemical proximate composition.

Chemical analysis of fish and diets

After slaughtering, all the fish were minced and sub-samples analysed for moisture content (60°C, 24h), nitrogen (protein = N x 6.25), and ash using standard procedures (AOAC, 1984). Another sub-sample was analysed for total lipid (using chloroform/ methanol as solvent) according to the method of Folch et al. (1957) as adapted by Christie (1982). These analyses were duplicated for each fish batch sampled. Similar methods were used for determining the chemical composition of the diets and diet ingredients. The gross energy was calculated on a dds CP500 bomb calorimeter. The Urease activity of the two soy products and diets was determined by the M/U65 method (AOCS, 1973).

TABLE 1
RATIO (%) AND COMPOSITION OF THE INGREDIENTS AND DIETS USED AND THE COST OF THE EXPERIMENTAL DIETS

Ingredients	Diets					
	Fish meal	Tomato	Soy-1	Soy-2	Yeast	Mix
Fish meal	47.0	37.0	14.0	8.0	25.0	6.0
Tomato		44.0				
Soy extruded			57.0			59.0
Soy extracted				60.0		
Yeast					52.0	15.0
Fish oil (cooked)	9.0	10.0	12.0	13.0	10.0	11.0
Maize	41.0	6.0	14.0	16.0	10.0	6.0
Binder	2.0	2.0	2.0	2.0	2.0	2.0
Vit/min (premix)	1.0	1.0	1.0	1.0	1.0	1.0
%-protein*	37.5	37.4	37.4	37.7	37.4	37.2
%-fat*	13.8	16.6	13.6	14.6	12.5	11.8
%-protein#	35.8	36.4	38.3	36.4	34.2	37.1
%-lipid#	15.3	17.1	15.0	14.8	13.0	12.6
Gross energy MJ/kg#	19.18	21.28	20.00	19.99	19.85	19.48
Urease activity#	0.02	0.02	0.07	2.20	0.04	0.02
P/E g/MJ GE	18.3	16.9	19.2	18.4	17.5	19.6
Diet components	**Fish meal**	**Tomato**	**Soy-1**	**Soy-2**	**Yeast**	**Maize**
%-protein#	71.9	23.3	45.8	50.9	35.6	9.0
%-lipid#	7.7	8.2	0.2	0.9	0.5	2.8
Cost/kg	2.40	1.66	3.56	3.29	1.91	3.41

*calculated, #analysed

Data analysis

A linear model was fitted to the data with diet as predictor. PROC GLM of the SAS package was used and an analysis of variance was carried out. Both a mean and standard error were calculated for each diet and a matrix of exceedance probabilities measured to test for pair-wise differences between diets (SAS, 1985). The least square mean (LSM) values of the final mass were used for calculations of the specific growth rates (SGR) using the following formulae (Castell and Tiews, 1980):

$$SGR = ((\ln W_t - \ln W_0)/t)^{*}100$$

W_t = LSM value of final mass after time t
W_0 = initial mean mass
t = time

The mean values for mass gain, SGR, and the proximate composition of the fish in each tank were then analysed and the differences between the diets (p 0.05) were established by a Duncan test. The associations between diet composition, mass gains and carcass compositions were tested by Pearson correlation analysis (SAS, 1985).

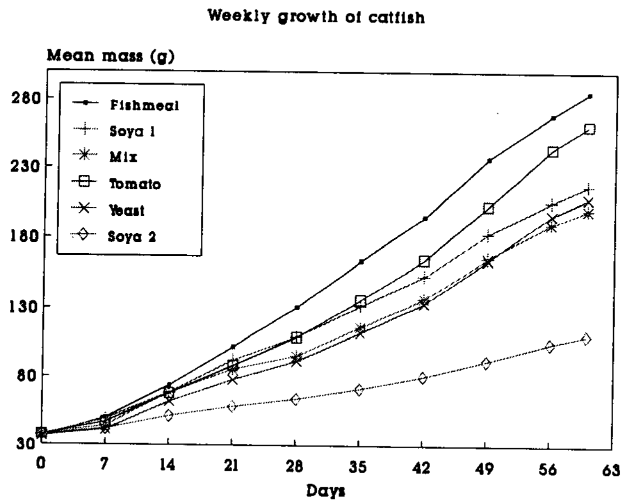

Figure 1
A diagrammatic presentation of the growth of C. gariepinus *fed diets containing different protein types*

TABLE 2
MEAN MASS ± SE AT THE BEGINNING OF THE EXPERIMENT, LSM MASS AT THE END OF THE EXPERIMENT, THE MASS GAIN IN GRAM AND THE SGR ± SE

Diet	Mean start mass	LSM final mass	Mean mass gain	SGR*
Fish meal	36.3 ± 0.3	284.6 ± 5.2[a]	248.3 ± 8.2[a]	3.43 ± 0.04[a]
Tomato	37.7 ± 0.4	261.9 ± 5.3[b]	224.1 ± 4.0[b]	3.23 ± 0.03[b]
Soy-1	37.3 ± 0.6	220.5 ± 5.2[c]	183.1 ± 5.4[c]	2.96 ± 0.06[cd]
Soy-2	37.8 ± 0.3	115.3 ± 5.5[d]	77.6 ± 5.1[d]	1.86 ± 0.07[e]
Yeast	36.6 ± 0.4	222.2 ± 5.7[c]	185.6 ± 11.0[c]	3.00 ± 0.08[c]
Mix	37.8 ± 0.7	201.4 ± 5.5[c]	163.5 ± 9.3[c]	2.78 ± 0.09[d]

Estimates within the same column sharing the same superscript letters do not differ significantly ($p \leq 0.05$).
*Calculated as $SGR=((\ln W_t - \ln W_0)/t)*100$, where W_t=LSM value of final mass after time t, W_0=initial mean mass.

TABLE 3
PROXIMATE CHEMICAL COMPOSITION OF WHOLE FISH (% WET MASS BASIS)

Diet	Moisture	Protein	Lipid	Ash
Fish meal	64.6 ± 1.68[b]	17.2 ± 0.91[a]	15.3 ± 0.55[a]	2.9 ± 0.43[a]
Tomato	67.3 ± 0.74[a]	16.4 ± 0.55[a]	15.0 ± 0.24[a]	3.0 ± 0.24[a]
Soy-1	67.7 ± 0.32[a]	17.1 ± 0.71[a]	13.2 ± 0.59[b]	2.7 ± 0.53[a]
Soy-2	69.1 ± 0.67[a]	17.9 ± 0.22[a]	11.5 ± 0.41[c]	3.8 ± 0.32[a]
Yeast	69.5 ± 0.59[a]	16.5 ± 0.64[a]	11.6 ± 1.05[bc]	3.0 ± 0.49[a]
Mix	69.5 ± 0.09[a]	18.0 ± 0.33[a]	11.4 ± 0.39[c]	2.8 ± 0.49[a]

Diets with the same superscript are not significantly different, $p \leq 0.05$
Five fish from each tank were pooled; in total 20 fish from each diet were analysed. Mean values ± SE, n=4

TABLE 4
THE FEED COSTS PER KG MASS GAIN PER DIET

Diet	R/kg
Fish meal	4.25
Tomato	2.79
Soy-1	7.09
Soy-2	10.01
Yeast	3.65
Mix	7.13

The cost calculations are given without taking into account the binder in the diets.

Results

There was no significant difference in the initial mass between and within the diets (p=0.1620), which all resulted in growth (Fig. 1), the control diet (fish meal) having the highest, followed by the tomato, Soy-1, yeast, mix and Soy-2 diets. The LSM final mass, mass gain and specific growth rates are summarised in Table 2. Significantly the fish meal diet gave the highest SGR (3.43 ± 0.04 g/d) which was markedly higher than that of the tomato (3.23 ± 0.03) and other diets. The fish fed on tomato had, on the other hand, significantly higher growth rates than fish on Soy-1, Soy-2, yeast and mix diets. The growth rates of fish on Soy-1 (2.96 ± 0.06) and yeast (3.00 ± 0.08) did not differ significantly from each other ($p \leq 0.05$), nor did the growth rates of fish on Soy-1 and mix (2.78 ± 0.09). Fish fed Soy-2 had the lowest growth rate of all (1.86 ± 0.07). Although no correlation was found between the measured amount of protein in the diets and the SGR, or the mass gain for the experimental groups, there was a strong positive correlation between these two parameters and the amount of fish meal in the diet (r = 0.74 and r = 0.81 respectively, p = 0.0001).

Overfeeding the fish was done purposely to ensure an absence of restrictive feeding, especially towards days 6 and 7, in the faster growing experimental groups. The feed intake was not measured and therefore it would not be correct to refer to a feed conversion ratio (FCR) as it is usually defined. However, the FCRs for the whole experimental period, as feed fed/mass gain, are: tomato 1.68, fish meal 1.77, yeast 1.91, Soy-1 1.99, mix 2.09, and Soy-2 3.04.

The defatted soybean meal called Soy-2 (extracted soybean meal) had a urease activity of 2.20, while that of the extruded soybean meal (Soy-1) had an index of 0.01. Of the diets, fish meal, tomato and mix had the lowest urease index (0.02) while that of the yeast diet was slightly higher (0.04). The Soy-1 diet had an index of 0.07 compared to 1.73 for the Soy-2 diet, the latter being the highest. Highly negative correlations were found between the SGR or mass gain and the urease activity of the diet (r = -0.9 and r = -0.8 respectively, $p \leq 0.0001$).

The chemical composition of the fish at termination of the experiment is shown in Table 3. A Duncan grouping showed no differences in the protein content of fish fed the varying protein diets, and there was greater diversity (SE) in the protein content of fish within the diets than between the six diets. A GLM analysis showed a significant effect of diets on the lipid content on the fish (R^2 = 0.81, $p \leq 0.0001$). The amount of body fat was significantly higher in the fish fed the fish meal and tomato diets (Table 3). The total amount of lipids in the body strongly correlated with the fat content of the experimental diets (r = 0.7, $p \leq 0.0003$).

The feed costs per kg mass gain in the 60 d duration of the experiment are summarised in Table 4. The tomato diet was the most economical (R2.79/kg mass gain), followed by the yeast diet (R3.65/kg mass gain).

Of the 600 fish stocked at the beginning of the experiment, 14 died, four of them coming from a single tank being fed the yeast diet. At termination of the experiment, the fish were examined for any abnormalities. A significantly ($R^2 = 0.073$, $p = 0.0009$) higher number of fish with gut erosion (Boon et al., 1987) were found among fish fed the yeast diet (n=8), the Soy-2 diet (n=7) and the other diets (mix = 2, fish meal = 1, Soy-1 = 1, tomato = 0).

Discussion

In this investigation, the amount of protein in the diets varied from 34.7 to 38.3%. This indicates that the variation in growth response is mainly due to the difference in suitability of the feed ingredients as components in the diets for African sharptooth *C. gariepinus* catfish. The specific growth rates (SGRs), and the corresponding mass gains in this investigation were generally good compared with other experiments with catfish of comparable size and analogous conditions (water temperature). In an experiment conducted by Balogun and Ologhobo (1989), where African catfish were fed soybean meals, much lower SGRs (0.02 to 0.2) were obtained. Degani et al. (1989) fed four different protein levels (25%, 30%, 35% and 40%) and three different main sources of protein (fish meal, soybean meal, and corn meal) to the same fish species, which resulted in higher SGRs (0.5 to 1.9) than those of Balogun and Ologhobo (1989) but lower than those of the present investigation.

The lack of correlation between the dietary protein content and the SGR or mass gain in the present investigation can be attributed to the small differences in the percentage of crude protein in the diets. The difference in SGRs between the diets can therefore possibly be attributed to the suitability (digestibility) of the protein types for the catfish. It is well known that the utilisation efficiency by fish of different protein types differs. For example, El-Sayed (1994) compared the utilisation efficiency of soybean meal, *Spirulina* meal, and chicken offal meal as protein sources for silver seabream (*Rhabdosargus sarba*) fingerlings and found that the *Spirulina* meal was utilised more efficiently than either soybean meal or chicken offal.

Henken et al. (1986) conducted a study with African catfish with a mean initial mass of 40g, looking at an optimal protein-energy ratio at different temperature levels. They found the optimal amount of crude protein per unit of metabolisable energy (ME) intake with respect to growth rate to be 25.4 g/MJ at 24°C (crude protein 49.4%, ME 19.5kJ/g). At 29°C this amount was 34.7 g/MJ (crude protein 65%, ME 18.7 kJ/g). The optimum protein-energy ratio was also found to be dependent on temperature. In their investigation, they used casein as a protein source. The SGRs they obtained (1.7) were all below the values achieved in this investigation. In the test diets of Henken et al. (1986), the amount of protein was higher than in the present investigation, suggesting that the protein content in their diets could be higher than the actual need of *C. gariepinus.*

The protein-energy ratio of the fish meal diet is higher than that of the tomato diet on a gross energy basis and similar to that of Soy-2. If the digestible or metabolisable energy values of the diets had been known, potential correlations between the growth rates and the energy levels could have been drawn. In this investigation, there was no correlation between the gross energy level and the SGRs of the different diets. Machiels and Henken (1985) conducted an investigation on the same fish species using three energy levels (8.4, 12.6 and 16.8 kJ calculated ME per gram feed used), and five protein levels based on casein as the main protein source (20, 25, 30, 35 and 40% protein). During their feeding experiment they found that 13 MJ of ME corresponded to 21 to 24 MJ of gross energy. For African catfish at 40 to 120g live mass it was shown that growth rate, protein gain and protein utilisation were better in response to 13 MJ/kg of ME in the diet than to either lower or higher levels of ME (8 and 17 MJ/kg respectively). In the present investigation, the gross energy of the six diets varied between 19.2 and 21.3 MJ and therefore covered the catfishes' energy needs.

The high food conversion ratio (FCR) indicates overfeeding. The feeding level was adjusted once a week and therefore, theoretically, the FCR would have been the same if the nutritional value of the diets had been the same. The fact that the FCRs differed indicates that the catfish utilised the feed ingredients at different levels. The low FCR recorded for the tomatoes (1.68) demonstrates that this diet has great potential and warrants further investigation. A possible reason why the catfish grew well on this particular tomato diet could be related to its high fish meal content (37.0% - Table 1). This content was 10% lower than that of the control fish meal diet. As noted, there was a high correlation (r=0.74) between the amount of fish meal in the diets and the SGRs. Also worth noting is that the maize content decreased from 41.0% in the control diet to 6.0% in the tomato diet. The amount of carbohydrates in the diets was not measured. According to Lovell (1989) and Wilson (1994), warm-water omnivore fish can digest and metabolise carbohydrates relatively well. Uys and Hecht (1987) report that *C. gariepinus* exhibits a high degree of pancreatic amylase activity; hence carbohydrates (starch) can form a significant part of the diet of this species. Unrecorded investigations in our laboratory have suggested that cooked maize in the diets of the catfish is not readily consumed. The use of tomato, especially as a carbohydrate replacement for cooked maize in the diets of catfish, warrants further investigation.

The difference in the SGR of the catfish on the two soybean meal products can most probably be attributed to the presence of anti-nutritional factors, especially trypsin inhibitor. This is emphasised by the difference in the urease activity, Soy-1 having an index of 0.07 compared to the 1.73 of Soy-2. Both these soybean meal products come from the same factory and only differ in their processing treatments. The higher heat experienced by the Soy-1 product destroyed most of the anti-nutritional factors. It is well recorded that heat treatment primarily inactivates the heat labile trypsin inhibitor and denatures the soy protein making them more digestible (Akiyama, 1989). However, the additional heating required to produce Soy-1 raises the cost of this product.

Feed intake was not monitored, but it was noted that the fish fed the fish meal and tomato diets were more eager to take feed. Whether this is due to the faster growth rates of these fish or a more palatable diet is not known.

Several studies on African catfish (Machiels and Henken, 1985; Henken et al., 1986; Bureau et al., 1995) have shown that the amount of protein in the diet influences the amount of body protein. In this investigation, the amount of dietary protein did not differ (Table 1). Similarly, the amount of whole body protein of the fish did not differ statistically ($p \leq 0.05$, Table 3). Shearer (1994) noted that in fish the amount of body fat is closely correlated to the amount of lipid in the diet. The whole body lipid content of the catfish from this investigation also showed a close correlation (r=0.7) with the dietary lipid.

The economy of feeding (Table 4) would have been improved if the fish had been fed simply to satiation and not overfed as in this experiment. The Soy-1 diet was not cheaper than the fish meal per kg feed (Table 1), nor did it prove cheaper to produce a kg of fish (Table 4). The fact that soy meal (Soy-1=R3.75/kg; Soy-2=R3.35/kg) is more expensive than fish meal (R3.30/kg) in South Africa could be attributed to the competition from livestock and humans for this food source. The growth obtained and production costs on the yeast diet were also disappointing; again the high cost here can be attributed to competition from livestock for this waste product. The low production cost of the tomato diet (R2.79/kg fish mass gain) shows, on the other hand, that this waste product has great potential. In South Africa tomatoes are grown in hot areas that are also suitable for catfish culture. The hot dry air also makes these areas suitable for sun-drying the tomatoes, a fact that could influence costs. At present, large quantities of tomato and tomato waste (pips and skins) are unused and could play an important role in lowering the production costs of catfish (the suppliers of the tomato process 200 $t \cdot d^{-1}$). The only likely problem is that producers might see potential for increasing their profit margin and thus make the tomato too expensive for the catfish farmers. However, at present this useful product has no financial value and could therefore be used in fish diets. More research is needed, however, to find the optimum level of tomato inclusion in African sharptooth catfish diets.

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