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PROTEIN TO ENERGY RATIOS IN AFRICAN CATFISH FED PURIFIED DIETS: IS *CLARIAS GARIEPINUS* (BURCHELL) AN ORDINARY CARNIVORE?

Panagiotis A. Pantazis

Department of Agriculture, Animal Production and Aquatic Environment, University of Thessaly, Fytokou Street, Nea Ionia Magnisias, 384 46 Volos, Greece

ABSTRACT. Six diets made from purified and semi-purified materials (casein, gelatin, gluten, zein, dextrin, α-cellulose) were tested over an 80-day period in adult (150 ± 47.40 g) African catfish, *Clarias gariepinus* (Burchell). Six protein to lipid ratios were tested ranging from 12.85 mg protein kJ^{-1} to 20.51 mg protein kJ^{-1}. Performance indices (PWG, SGR, FCR) compare favorably with those previously observed for *C. gariepinus* and other clariid species. The best performing diets were those with a total gross energy range of 22 to 24 kJ g^{-1}, a P/E ratio of 19.5-20.5 mg protein kJ^{-1}, a crude protein level of 46%, a crude lipid level of 10-17%, and a carbohydrate level of 26-32%. The carbohydrate levels (26-32%) of the best performing diets during these experiments were much higher than those of previous researchers (16-18%) for the same species and still higher than those (15-25%) employed for other carnivores (salmonids, sea bass, sea bream). Therefore, African catfish possibly exhibits more efficient dietary carbohydrate utilization. An increase in carcass lipid as a result of increased dietary non-protein energy was also recorded.

Key words: AFRICAN CATFISH (*CLARIAS GARIEPINUS*), CARBOHYDRATE UTILIZATION, CARCASS QUALITY, NUTRITION

INTRODUCTION

Better food utilization is not only the result of increased protein level, but also of improved protein quality. Protein quality is inter-related to energy utilization; therefore, replacing good quality dietary protein with lipid or carbohydrate might create a protein-sparing effect (Watanabe et al. 1979, Nematipour et al. 1992, Cowey 1993). On the other hand, excessive dietary energy can lead to increased lipid deposition (Watanabe 1982), the deterioration of carcass quality (Haard 1992, Nakagawa and Kimura 1993, Shahidi et al. 1992), and reduced growth (Daniels and Robinson 1986). Ratios of digestible protein to digestible energy for maximum weight gain of several fish

CORRESPONDING AUTHOR: Panagiotis A. Pantazis, University of Thessaly, Department of Agriculture, Animal Production and Aquatic Environment, Fytokou Street, Nea Ionia Magnisias, 384 46 Volos, Greece, Tel./Fax: (30) 421-93259, (30) 24210 93157; e-mail: papantaz@uth.gr

species range from 19.35 mg protein kJ^{-1} to 27.96 mg protein kJ^{-1} (NRC 1993). These ratios are substantially higher than those for swine and poultry (9.55 to 14.34 mg protein kJ^{-1}; NRC 1984, 1988), as fish require less energy for maintenance (NRC 1993).

Previous research on African catfish, *Clarias gariepinus* (Burchell), nutrition showed its obvious trend for carnivory, while lipid utilization indicated a protein sparing effect (Machiels and Henken 1985, Ufodike and Ekokotu 1986, Degani et al. 1989, Uys 1989, Fagbenro and Nwanna 1999). Furthermore, digestibility experiments indicated that adult *C. gariepinus* accept purified diets comprised mainly (48-50%) of purified proteins with high digestibility values for most nutrients (Pantazis and Neofitou 2004).

In the present study, it was decided to investigate the utilization of carbohydrates affected by varying P/E ratios by using purified diets. A more in-depth investigation of the biochemical composition of vital body organs (liver) coupled with blood glucose levels and performance parameters would better elucidate the utilization of carbohydrates and other dietary nutrients and facilitate decisions regarding the balanced dietary profile of the cost-effective diet.

MATERIAL AND METHODS

ANIMALS, HUSBANDRY, THE EXPERIMENTAL SYSTEM AND THE EXPERIMENTAL DESIGN

The fish originated from the African catfish stock of the Institute of Aquaculture, University of Stirling, Scotland. Seventy nine fish were allocated to eighteen 50 l cylindrical tanks. These tanks were part of a recirculating water system. The specimens were anesthetized with benzocaine (ethyl para-aminobenzoate) at a concentration of 0.05 g l^{-1} (Ross and Ross 1983). Six treatments were triplicated according to the randomized block experimental design (Woolf 1968, Zar 1996) in which plots are allocated within each block to the number of treatments (3 blocks × 6 treatments = 18 tanks). The initial mean individual body weight of the experimental fish ranged between 150 and 171 g (Table 1). Before comparing the mean weight of each group with multiple range tests, Bartlett's test for homogeneity of variances (Zar 1996) was employed with the initial weight of all the groups in order to assess the validity and strength of the expected results.

The fish were sampled at the beginning and end of the 80-day experiment. After the final sampling, all the fish were euthanized and the carcasses were frozen (-20°C) for further analyses.

TABLE 1

Initial body weight (g), initial stocking density, and performance indices of the various groups after 80 days (mean (SD))*

Group/Diet[1]	Body wet weight (g)	Stocking density (g l^{-1})	SGR[2]	TGC[2]	Weight gain (%)	Weight Gain** (%)
Group1/32:10	171.03[a] (32.97)	3.42[a] (0.86)	0.32[d] (0.13)	0.018[b] (0.009)	28.45 [d] (13.57)	31.69[c] (8.75)
Group2/32:16	158.73[a] (39.58)	3.16[a] (0.79)	0.37[d] (0.15)	0.020[b] (0.008)	35.04 [d] (15.39)	35.90[c] (9.36)
Group3/40:10	151.08[a] (60.82)	3.02[a] (1.21)	0.44[c] (0.15)	0.021[b] (0.005)	40.75 [b] (15.74)	39.36[b] (9.54)
Group4/40:16	150.40[a] (56.50)	3.01[a] (1.13)	0.49[c] (0.12)	0.025[b] (0.007)	46.53 [b] (14.01)	42.95[b] (8.14)
Group5/46:10	169.40[a] (40.76)	3.38[a] (1.21)	0.55[b] (0.11)	0.031[a] (0.007)	52.23 [b] (12.67)	46.35[b] (7.43)
Group6/46:16	152.83[a] (54.59)	3.06[a] (1.09)	0.60[a] (0.19)	0.032[a] (0.009)	59.27 [a] (22.48)	50.60[a] (13.89)
SD***	47.40	0.98	0.24	0.012	25.49	25.49

[1] *See Table 2*

[2] *SGR= Specific Growth Rate (Steffens 1989); TGC = Thermal Growth Coefficient (Cowey 1992)*

**Values in the same column and with the same superscript are not significantly different (P > 0.05)*

*** Expressed as the arcsine transformed numbers of the real weight gain percentages*

**** Standard deviation of the multiple comparisons*

The water temperature was 26-27°C, the photoperiod was 12:12 (L:D), and the oxygen level range was 4.0-4.5 mg l^{-1}. The experimental tanks were part of a recirculating system, which was sampled at two-week intervals to assess water quality. Water quality sampling and analyses were performed as described in Pantazis and Neofitou (2003).

FEEDS AND FEEDING

Six diets comprised of purified materials were prepared and used in this experiment. The composition and proximate analyses of the diets is presented in Table 2. Diet formulation was based on previously established successful formulations comprised of purified materials; this provides a greater degree of ingredient control than is possible with complex foodstuffs (fishmeal, soy, wheat, maize, carcass meal, blood meal) (Uys 1984, 1989, Machiels and Henken 1985). The preparation of the diets and the raw materials used are described in Pantazis and Neofitou (2003). Vitamin and mineral premixes were also employed.[1]

Prior to the start of the experiment, the fish were acclimated to the purified diets for 20 days with the maintenance diet (Table 2). Feeding with the experimental diets began

[1] Composition of vitamin premix (g 100 g^{-1} premix): cyanocobalamin (B12) – 0.000125; ascorbic acid – 3.75; cholecalciferol (D) – 0.0004; tocopherolacetate (E) – 0.7; vitamin K – 0.15; thiamine hydrochloride (B1) – 0.425; riboflavin (B2) – 0.3; pyridoxine hydrochloride (B6) – 0.125; calcium pantothenate – 0.525; niacinamide – 1.25; biotin – 0.009; folic acid – 0.1; choline chloride – 7.4; myoinositol – 0.25; ethoxyquin – 0.0019; vitamin A – 0.008; α-cellulose – 85. Composition of the mineral premix (g 100 g^{-1} of each salt in premix): $CaHPO_4 \times 2H_2O$ – 72.77; $MgSO_4 \times 7H_2O$ – 12.75; NaCl – 6; KCl – 5; $FeSO_4 \times 7H_2O$ – 2.5; $ZnSO_4 \times 7H_2O$ – 0.55; $MnSO_4 \times 4H_2O$ – 0.25; $CuSO_4 \times 5H_2O$ – 0.078; $CoSO_4 \times 7H_2O$ – 0.047; $CaIO_3 \times 6H_2O$ – 0.029; $CrCl_3 \times 6H_2O$ – 0.012

following a 4-day starvation period (Kaushik 1979). The daily ration size and feeding regimes were determined as suggested in Pantazis and Neofitou (2003).

The raw materials and diets were prepared for analyses as described in Pantazis and Neofitou (2003). The moisture content, protein, crude lipid, crude fiber, carbohydrates (CHOs), ash, and energy in the raw materials and the prepared diets were determined as described by Pantazis and Neofitou (2003). Liver lipid was determined with the method in Folch et al. (1957) and liver glycogen with anthrone-sulphuric acid reagent as initially described by Good et al. (1933) and later modified by Seifter et al. (1950) and Hassid and Abraham (1957).

TABLE 2

Composition and proximate analyses of diets (% of dry matter)[1]

Nutritional profile	Diet 1 32:10	Diet 2 32:16	Diet 3 40:10	Diet 4 40:16	Diet 5 46:10	Diet 6 46:16	Maintenance
Casein	19.5	19.5	27.5	27.5	31	31.0	18.0
Gelatin	5.0	5.0	4.5	4.5	6.5	6.5	5.0
Gluten	8.0	8.0	8.5	8.5	8.0	8.0	7.0
Zein	3.0	3.0	3.5	3.5	3.5	3.5	3.0
Dextrin	44.5	38.5	36.0	30.5	31.0	25.5	47.0
α–cellulose	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Carboxymethylcellulose	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Vegetable oil [(2)]	5.0	8.0	5.0	8.0	5.0	8.0	5.0
Fish oil [(2)]	5.0	8.0	5.0	7.5	5.0	7.5	5.0
Vitamin premix [(2)]	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Mineral premix [(2)]	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Dry matter	86.67 (0.16)	88.65 (0.04)	85.82 (0.002)	94.81 (0.06)	92.05 (0.33)	91.62 (0.22)	91.66 (0.03)
Crude protein	31.93 (0.28)	30.78 (0.04)	41.32 (0.35)	40.32 (0.11)	45.98 (0.05)	46.26 (1.31)	28.16 (0.18)
Crude lipid	9.64 (1.24)	17.10 (0.70)	10.75 (1.04)	17.50 (1.12)	11.65 (0.82)	16.58 (0.07)	8.36 (1.13)
Carbohydrates	48.92 (0.34)	41.33 (0.48)	42.71 (0.78)	36.88 (0.13)	31.39 (1.08)	26.42 (0.74)	52.75 (1.63)
Ash	4.15 (0.06)	5.35 (2.04)	4.17 (0.005)	4.07 (0.06)	5.55 (2.29)	5.19 (1.22)	5.44 (1.88)
Crude fiber	5.34 (0.26)	5.35 (0.26)	5.22 (0.32)	5.3 (0.48)	5.43 (0.18)	5.32 (0.29)	5.32 (0.53)
Gross energy (kJ g^{-1})	22.77	23.95	23.06	24.47	22.42	23.75	22.59
Digestible energy[(3)] (kJ g^{-1})	18.85	19.83	19.09	20.25	18.56	19.66	18.7
Protein: energy ratio (mg protein kJ^{-1})	14.03	12.85	17.92	16.48	20.51	19.48	12.46

[1] *Numbers in parenthesis represent standard deviation (n=3). Source of raw materials used as described in the text*
[2] *Composition of vitamin and mineral premixes and source of oils as described in the text*
[3] *Digestible energy values were estimated according to digestibility experiments (Pantazis and Neofitou 2004)*

HEMATOLOGY

Sampling for all hematological parameters was performed eight hours after the last feeding and just before the termination of the trial. Blood samples of 0.5 to 1.00 ml were collected from the caudal artery in a non-heparinized syringe and transferred into heparinized 1.5 ml Eppendorfs with sodium fluoride and stored in crushed ice.

Plasma blood glucose was determined with the glucose oxidase method (Sigma Kit; Trinder 1969) from aliquots of the heparinized Eppendorfs containing sodium fluoride (to minimize glycolysis due to glucose consumption by blood cells). A UVIKON 810 / KONTRON spectrophotometer was used. The blood glucose of each group was estimated as the arithmetic mean of values for all the fish within that group.

PERFORMANCE EVALUATION AND STATISTICAL ANALYSIS

The performance indices used in this experiment were as follows: Specific Growth Rate (SGR) (Steffens 1989); Thermal Unit Growth Coefficient (TGC) (Cowey 1992); Percentage Weight Gain (PWG) (Steffens 1989); Food Conversion Ratio (FCR) (Steffens 1989); Feed Intake (FI); Protein Efficiency Ratio (PER) (Steffens 1989); Apparent Net Protein Utilization (ANPU) (Bender and Miller 1953); Hepatosomatic Index (HI) (Pfeffer et al. 1991).

Performance indices were estimated using cumulative tank data by estimating the total ration and fish weight gain collectively for the biomass of each tank. In addition, the fish in all the experimental groups were analyzed for liver glycogen and liver lipid. Carcass analyses were performed in triplicate for each individual within a treatment-group. The final values for each group represent the arithmetic mean of individual values within that group.

SPSS for Windows Statistical Software Package was used. Multiple comparisons were made using Duncan's multiple range test. For the statistical evaluation of PWG and ANPU, percentages were arscine transformed (Zar 1996).

RESULTS

PHYSICOCHEMICAL PARAMETERS, PERFORMANCE INDICES, CARCASS COMPOSITION, AND BIOCHEMICAL COMPOSITION OF THE LIVER

During the 80 days of the experiment, water samples were collected five times and the water quality values were as follows: nitrites 0.2 ± 0.05 ppm; nitrates 19.28 ± 4.84 ppm; unionized ammonia 0.75 ± 0.06 ppm; pH 7.07 ± 0.05.

The average initial tank weights of the experimental population were insignificantly different (P > 0.05) (Table 1). Statistical comparisons with the Bartlett's test revealed no statistical differences among the average initial body weight of all the groups and indicated the homogeneity of variances within the experimental population ($\chi^2_{0.05;\ 8} = 15.507$; $0.9 < P < 0.95$).

Performance indices (Table 1) suggest that Group 6, which was fed the high protein-high energy diet (46:16), had significantly higher (P < 0.05) SGR and PWG than the other groups.

TABLE 3

Established feed intake levels and feed and protein utilization indices for the overall 80-day experimental period* (mean (SD))

Group/Diet	Feed Intake[1]	FCR [2]	PER [2]	ANPU [2]
Group1 / 32:10	0.84 [b] (0.12)	2.25 [a] (1.09)	1.57 [c] (0.76)	22.75 [b] (8.32)
Group2 / 32:16	0.87 [b] (0.22)	2.31 [a] (1.53)	1.81 [b] (1.20)	17.61 [c] (2.65)
Group3 / 40:10	1.09 [a] (0.65)	2.01 [a] (0.66)	1.27 [c] (0.42)	18.77 [c] (2.57)
Group4 / 40:16	0.88 [b] (0.08)	1.66 [c] (0.32)	1.52 [c] (0.29)	18.67 [c] (9.27)
Group5 / 46:10	0.65 [c] (0.31)	1.07 [b] (0.65)	2.49 [a] (1.53)	42.26 [a] (7.77)
Group6 / 46:16	0.77 [c] (0.10)	1.19 [b] (0.35)	1.81 [b] (0.53)	27.10 [b] (9.70)
SD**	0.27	0.8	0.85	7.61

[1] *Expressed as % of live weight day^{-1}*

[2] *FCR= Food Conversion Ratio / PER = Protein Efficiency Ratio / ANPU = Apparent Net Protein Utilization (arcsine transformed data)*

**Values in the same column and with the same superscript are not significantly different (P > 0.05)*

*** Standard deviation of multiple comparisons*

Fish fed the 46:10 diet (Group 5) were characterized by better protein utilization (ANPU; Table 3) and higher carcass protein contents than the other groups (Table 4), whereas their carcass lipid levels were lower than those fed the 46:16 diet (Group 6). The comparison of hepatosomatic indices (Table 4) revealed some statistical differences among the various experimental groups.

TABLE 4

Comparison of the carcass protein, carcass lipid levels (% of dry matter (DM) basis), and the hepatosomatic index among the various experimental groups* (mean (SD))

Group/Diet	Carcass protein	Carcass lipid	Hepatosomatic Index
Group 1 /32:10	62.54 [b] (1.63)	16.69 [e] (0.58)	1.71 [b] (0.13)
Group 2 /32:16	60.00 [c] (1.16)	23.68 [b] (0.41)	1.57 [c] (0.16)
Group 3 /40:10	59.15 [c] (1.69)	26.18 [a] (0.65)	1.60 [c] (0.11)
Group 4 /40:16	61.19 [b] (2.62)	19.24 [d] (0.96)	1.88 [a] (0.12)
Group 5 /46:10	66.79 [a] (2.64)	14.15 [f] (0.48)	1.64 [c] (0.14)
Group 6 /46:16	62.56 [b] (3.04)	21.66 [c] (1.53)	1.56 [c] (0.23)

** Values in the same column and with the same superscript are not significantly different (P > 0.05), (n=12-15)*

Glycogen levels and lipid composition are presented in Table 5. Group 1 (fed a diet of 32% protein; 48.92% CHOs; 22.7 kJ g^{-1} energy), Group 3 (fed a diet of 40% protein; 42.7% CHOs; 23 kJ g^{-1} energy) and Group 5 (fed a diet of 46% protein; 31.39 CHOs; 22.4 kJ g^{-1} energy) were characterized by increased levels of liver glycogen. On the contrary, the distribution of liver glycogen levels within groups fed the same protein level was erratic. In addition, liver lipid values did not show any cohesive pattern related to the origin of dietary energy.

Some significant differences ($P < 0.05$) were noted in the feed intake levels among the various treatments (Table 3). Groups fed the high protein diet experienced better FCR and lower feed intake than did the other groups.

HEMATOLOGICAL PARAMETERS

The blood glucose levels were uniform among the fish from the same experimental group, whereas statistical differences were observed between the high and low energy diets at the 46% crude protein level (Table 5).

TABLE 5

Comparison of blood glucose (mg dl^{-1}), liver lipid, and liver glycogen (g $100g^{-1}$ DM) among the various groups* (mean (SD))

Group/Diet	Blood glucose values	Liver lipid	Liver glycogen
Group1 /32:10	48.53 ^{d} (3.25)*	12.86 ^{d} (1.27)	24.26 ^{d} (12.20)
Group2 /32:16	51.29 ^{cd} (10.4)	30.59 ^{a} (4.96)	9.71 ^{e} (4.10)
Group3 /40:10	58.58 ^{c} (4.37)	27.25 ^{b} (6.76)	44.50 ^{c} (10.25)
Group4 /40:16	58.33 ^{c} (6.16)	24.98 ^{b} (3.60)	64.89 ^{a} (8.92)
Group5 /46:10	129.42 ^{a} (1.83)	15.88 ^{d} (2.45)	60.16 ^{b} (9.42)
Group6 /46:16	109.26 ^{b} (2.55)	19.34 ^{c} (2.57)	44.66 ^{c} (4.31)
SD**	28.75	22.81	19.05

**Values in the same column and with the same superscript are not significantly different (P>0.05), (n=12-15)*
*** Standard deviation of the multiple comparisons*

DISCUSSION

The recorded water quality values were quite acceptable for the African catfish as it has been shown that this species is able to tolerate levels up to 8.8 ppm $N\text{-}NH_4$, 10-15 ppm $N\text{-}NO_2$, and 300 ppm $N\text{-}NO_3$ even at the larval stage (Viveen et al. 1986). In addition, oxygen levels cannot be considered critical for the air-breathing African catfish at the size range used in this experiment (Greenwood 1955, Haylor and Oyegunwa 1993).

The better performance indices (SGR and PWG) observed by previous researchers (Table 6) for experimental periods of almost identical duration may be a reflection of the lower initial weight of the fish used in those experiments combined with the administration of diets made from complex foodstuffs (increased consumption due to increased palatability and/or acceptability). However, the PWG, SGR, and FCR noted in this experiment compare favorably with the values of these parameters observed previously for *C. gariepinus* or other clariid species of the same size range fed purified or semi-purified diets (Machiels and Henken 1985, Dehadrai and Mukhopadhyay 1987, Khan and Jafri 1990, Baras et al. 1998).

TABLE 6

Comparison of various performance indices between this experiment and experiments by other researchers

Experiments	SGR	Weight Gain (%)	FCR	PER
Group 9 / Control; this experiment	0.84	79.73	1.28	2.50
Group 5 / 46:10; this experiment	0.55	52.23	1.07	2.49
Group 6 / 46:16; this experiment	0.60	59.27	1.19	1.81
Ufodike and Ekokotu (1986)[1]	1.2	160.0	2.43	0.8
Degani et al. (1989)[2]	1.31	127.14	2.31	1.43
Degani et al. (1989)[3]	1.44	203.6	1.35	1.87
Uys 1989[4]	5.42	212.1	0.95	2.46

[1] *84-day experimental period for the range of 20-60 g. The proximate analysis of this diet was: protein 50.2%; fat 10.6%; crude fiber 5.0%; ash 9.1%; carbohydrates 10.3%; gross energy 18.22 k J* g^{-1}. *The composition was algae 32%, cow blood meal 52%, groundnut oil 6.0%, cod liver oil 4.0%, minerals 2.0%, vitamins 2.0%, starch 1.5%,* Cr_2O_3 *0.5%*

[2] *78-day experimental period for the range of 10-37 g. The proximate analysis of the diet was: protein 30.0%; fat 2.4%; crude fiber 11.0%; ash 10.0%; carbohydrates 42%; gross energy 10.46 kJ* g^{-1}. *The composition of the diet was fishmeal 8.96%, soyabean meal 43.42%, corn meal 37.52%, cellulose 8.19%, vitamins 1.0%, guar gum 1.0%*

[3] *78-day experimental period for the range of 10-7 g. The proximate analysis of the diet was: protein 34.9%; fat 3.5%; crude fiber 10.8%; ash 9.8%; carbohydrates 40.12%; gross energy 10.46% kJ* g^{-1}. *The composition of the diet was fishmeal 17.03%, soyabean meal 43.94%, corn meal 29.03%, cellulose 8.0%, vitamins 1.0%, guar gum 1.0%*

[4] *21-day experimental period for groups of 1.0 to 160g. The proximate analysis of the diet was: protein 43%; fat 13.25%; crude fiber 1.74%; NFE 18.36%; ash 14.8%; gross energy 20.0 kJ* g^{-1}. *The composition of the diet was corn 5.4%, wheat bran 5.4%, fishmeal 52.9%, carcass meal 5.0%, blood meal 5.0%, fish oil 6.9%, vitamins 0.2%, minerals 0.2%, molasses powder 19.0%*

Protein utilization and protein carcass deposition was higher at a high P/E ratio (Diet 46:10 – 22.74 mg protein kJ^{-1}) with a concomitant decrease in the carcass lipid levels. This reconfirms the findings of Machiels and Henken (1985) who observed excess carcass lipid incorporation after the administration of a high energy (24 kJ g^{-1}), low P/E ratio diet (7.9-16 mg protein kJ^{-1}) with crude dietary lipid levels ranging between 20 and 24%, carbohydrate levels between 16% and 16.5%, and within a protein range of 19 to 38.5% of the diet (based on dry matter). Similarly, Degani et al.

(1989) concluded that increased dietary protein increases carcass protein retention and protein efficiency and decreases lipid in the muscles. This suggests that more research is needed on the topic of the protein-sparing action of fat. It is evident that the increase in carcass lipid due to increased dietary non-protein energy demonstrated for other species, *i.e.*, rainbow trout, *Oncorhynchus mykiss* (Walb.), channel catfish, *Ictalurus punctatus* (Raf.), common carp, *Cyprinus carpio* L., red drum, *Sciaenops ocellatus* (L.), and rabbitfish, *Siganus canaliculatus* (Park)(Garling and Wilson 1977, Takeuchi et al. 1979, Mohsen and Lovell 1990, Serrano et al. 1992, Osman et al. 1996, Jobling et al. 1998), was also demonstrated for African catfish in the present experiment.

Blood glucose levels in the current experiment were within the "normal" range of blood glucose values for rainbow trout (Alexis et al. 1985, Kaushik et al. 1989). Although groups 1, 2, 3, and 4 were fed decreasing levels of dietary carbohydrates (49, 41, 43, and 37%, respectively) at almost equal energy levels, they had equally low blood glucose levels. This is indicative of carbohydrate utilization similar to that of carp whose blood glucose is the result of gluconeogenesis from dietary amino acids (Nagai and Ikeda 1971a, b, 1972). Furthermore, groups 5 and 6, which were fed lower dietary carbohydrate levels (31.0 and 26.5%, respectively) than groups 1, 2, 3, and 4 at almost the same dietary energy levels (22.4-23.7 kJ g^{-1}) and similar dietary lipid levels, were characterized by the highest blood glucose levels most probably as a result of the highest protein levels (46%) in their diets. The liver glycogen levels in all the experimental groups partially reconfirm the blood glucose picture, as groups 5 and 6 (high dietary protein levels 46%) had higher levels of liver glycogen than groups 1 and 2; this probably resulted from higher liver glyconeogenesis from amino acid precursors (Bergman and Heitmann 1980). However, this was not the case with group 3, which had equal levels of liver glycogen compared to group 6 that was fed the high protein-high lipid diet and group 4 that was characterized by the highest liver glycogen values of all the groups.

Rainbow trout and Atlantic salmon, *Salmo salar* L., have the ability to store excess dietary carbohydrates in the liver (within a certain range) (Bergot 1979, Kaushik et al. 1989, Hemre et al. 1995). Although African catfish can store liver glycogen, this is rather of gluconeogenic origin from amino acid precursors while dietary carbohydrates are utilized as an immediate energy-yielding source rather than as stored fuel. This view is supported by the results of this experiment, in which groups administered high carbohydrate

diets exhibited better ANPU than those fed low carbohydrate-high lipid diets (with the same protein levels). Although excessive gluconeogenesis may be a negative factor in protein utilization in carnivores, carbohydrate levels (26-32%) of the best performing diets during these experiments were much higher than those applied by previous researchers (16-18%) for the same species and still higher than those (15-25%) employed with other carnivores (salmonids, European seabass, *Dicentrarchus labrax* (L.), sea bream, *Sparus aurata* L.; NRC 1993).

Therefore, African catfish possibly shows more efficient dietary carbohydrate utilization. The protein-sparing effect of dietary carbohydrates coupled with significantly higher carbohydrate digestibility (high pre-feeding intestinal amylase activity; Uys 1989) advocates the more comprehensive use of carbohydrates in catfish diet formulation. More experimentation is needed (by using labeled substrates) in order to clarify the utilization of carbohydrates, gluconeogenesis from amino acid precursors, and lipogenesis from both protein and carbohydrate precursors.

Garling and Wilson (1977) demonstrated that *I. punctatus* performs better with diets that have a carbohydrate: lipid (CHO:L) ratio between 0.0 and 4.5, whereas diets with ratios between 11.5 and 31.5 were less efficiently used. Jantrarotai et al. (1994) demonstrated that hybrid Clarias (*C. macrocephalus* × *C. gariepinus*), which were fed semi-purified diets whose carbohydrate originated mainly from broken rice, were able to tolerate up to 50% CHO and a CHO:L level of up to 11.23:1. In the present experiment, the CHO:L ratios for the best performing *C. gariepinus* groups varied from 1.59 to 2.69, whereas beyond this point decreased liver glycogen and overall performance were observed. However, no assumptions can be made for the CHO:L ratios in this experiment due to the lack of replication and the inappropriate experimental design for the combinations of these nutrients.

SUMMARY

C. gariepinus of 150-171 g of body weight performed best when fed diets containing a gross energy of 22-24 kJ g^{-1}, a P/E ratio of 19.5-20.5 mg protein kJ^{-1}, 46% crude protein, 10-17% crude lipid, and 26-32% carbohydrate. These diets indicate the better use of protein (sparing effect) as a result not only of lipid but also of better dietary carbohydrate utilization compared to those used by Uys (1989) and

Machiels and Henken (1985). The adaptation of this carnivore to increased dietary carbohydrates reflects its nutritional versatility and its unique standing among other cultured carnivore species. Furthermore, an increase in carcass lipid as a result of increased dietary non-protein energy was demonstrated in African catfish as it also has been for other species.

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STRESZCZENIE

EFEKTY ŻYWIENIA SUMA AFRYKAŃSKIEGO PASZAMI O RÓŻNYM STOSUNKU BIAŁKO-ENERGIA: CZY *CLARIAS GARIEPINUS* (BURCHELL) JEST ZWYCZAJNYM DRAPIEŻNIKIEM?

Celem badań było określenie wpływu żywienia młodocianego suma afrykańskiego, *Clariais gariepinus* (Burchell) sześcioma eksperymentalnymi paszami zawierającymi następujące ilości (% masy suchej) białka i tłuszczu: pasza 1 (32:10), pasza 2 (32:16), pasza 3 (40:10), pasza 4 (40:16), pasza 5 (46:10), pasza 6 (46:16) (tab. 2) na podstawowe wskaźniki hodowlane, chemiczny skład ciała i parametry hematologiczne. W obiegu recyrkulacyjnym przeprowadzono 80-dniowy podchów suma (objętość basenów podchowowych 50 l) o początkowej masie ciała 150 ± 47,40 g (tab. 1) – każdy wariant eksperymentalny (paszowy) podchowywano w trzech powtórzeniach. Najkorzystniejsze wartości wskaźników hodowlanych (np. względne tempo wzrostu masy ciała (SGR; % d^{-1}), współczynnik pokarmowy pasz (FCR), współczynnik wydajności wzrostowej białka (PER)), uzyskano w grupach żywionych paszami o zawartości energii brutto 22-24 kJ g^{-1}, stosunku białko-energia 19,5-20,5 mg białka kJ^{-1}, zawartości białka 46%, tłuszczu 10-17% i węglowodanów 26-32% (tab. 3). Poziom węglowodanów (26-32%) był istotnie wyższy niż w innych eksperymentalnych paszach stosowanych do podchowu tego gatunku (16-18%), czy też w paszach stosowanych do podchowu innych gatunków ryb drapieżnych (np. łososiowate, labraks, dorada). Wydaje się więc, że sum afrykański posiada efektywniejszy system utylizacji węglowodanów. Stwierdzono również istotny wpływ testowanych pasz na chemiczny skład ciała (szczególnie poziom tłuszczu) i parametry krwi suma afrykańskiego (tab. 4 i 5).