Nutrition and growth in *Clarias* species – a review

Jan H. Van Weerd

Department of Fish Culture and Fisheries, Wageningen Agricultural University, P.O. Box 338, 6700 AH Wageningen, The Netherlands.

Accepted January 23, 1995.

Van Weerd J. H. *Aquat. Living Resour.*, 1995, **8**, 395-401.

Abstract

The paper summarizes aspects of nutrition and growth in *Clarias* species. Of the many *Clarias* species cultured, *Clarias gariepinus* has been subject to particularly intensive research; the species has been widely introduced for aquaculture outside its natural range. *Clarias* are omnivorous fish. Their dietary protein requirements are about 40%, their energy requirements range between 13 and 17 kJ.g^{-1}. Controversy exists on their ability to utilize carbohydrates, despite the fact that their natural feed may contain high levels of carbohydrates. Comparison of growth performances as recorded in literature indicate that *C. gariepinus* seems to perform better in terms of growth rates and feed conversion than other species (*C. isheriensis*, *C. batrachus*, *C. fuscus*). Monosex culture (in *C. gariepinus*) or triploidy (in *C. gariepinus* and *C. batrachus*) do not seem to hold much future for improving growth and feed utilization, in contrast to hybridization. Selection for improved growth could have drawbacks, such as an increased level of agression. To achieve improved growth, selection for lower maintenance requirements or better glucose metabolization seems preferable over selection for high feed utilization efficiencies.

Keywords: Catfish, *Clarias*, Clariidae, Siluriformes, nutrition, growth.

Nutrition et croissance de Clarias *sp. – une synthèse.*

Résumé

L'article résume les aspects nutritionnels et de croissance chez les poissons du genre *Clarias*. Des nombreuses espèces cultivées de *Clarias*, *Clarias gariepinus* est particulièrement l'objet de recherche intensive; l'espèce a été largement introduite à des fins d'aquaculture hors de son son aire de répartition naturelle. *Clarias* est un poisson omnivore. La demande nutritionnelle en protéine est d'environ 40 % et celle en énergie est de 13 à 17 kJ.g^{-1}. Des controverses existent sur leur capacité à utiliser les sucres, en dépit du fait que leur alimentation naturelle contient des niveaux élevés en hydrates de carbone. Les comparaisons des performances de croissance, d'après une étude bibliographique, indiquent que *C. gariepinus* semble avoir de meilleures performances, en termes de taux de croissance et de taux de conversion alimentaire que les autres espèces (*C. isheriensis*, *C. batrachus*, *C. fuscus*). L'élevage de *C. gariepinus* en séparant mâles et femelles ou l'élevage d'individus triploïdes (chez *C. gariepinus* et *C. batrachus*) ne semblent pas ouvrir de larges perspectives pour améliorer la croissance et l'utilisation nutritionnelle, contrairement à l'élevage d'hybrides. La sélection pour améliorer la croissance pourrait provoquer des inconvénients telle que l'augmentation du niveau d'agressivité. Pour parfaire l'amélioration de la croissance, la sélection pour des demandes plus faibles de maintenance ou de meilleure métabolisation du glucose semble préférable à une sélection pour l'efficacité d'une forte utilisation nutritionnelle.

Mots-clés : Poisson-chat, *Clarias* sp., Clariidés, Siluriformes, nutrition, croissance.

INTRODUCTION

A variety of species of the genus *Clarias* and their hybrids is cultured, for reasons of their high growth rate, disease resistance and amenability to high density culture, related to their air-breathing habits (Huisman and Richter, 1987; Haylor, 1993). Of the species studied, a.o. *Clarias macrocephalus* (Areerat, 1986), *Clarias batrachus* (*e.g.* Zheng *et al.*, 1988; Singh and Singh, 1992), *Clarias fuscus* (Zheng *et al.*, 1988; Anderson and Fast, 1991) and *Clarias isheriensis* (*e.g.* Fagbenro and Sydenham, 1989), the African species *C. gariepinus* has been subject to particularly intensive research in notably S. Africa (*e.g.* Hecht *et al.*, 1988) and the Netherlands (*e.g.* Huisman and Richter, 1987). *C. gariepinus* has been widely introduced for aquaculture outside its natural range (Verreth *et al.*, 1993). Recent reports on the status of commercial culture of *Clarias* species are given for Thailand by Areerat (1987), for China by Zheng *et al.* (1988), for southern Africa by Hecht *et al.* (1988) and for the Netherlands by Verreth and Eding (1993). The present paper summarizes aspects of nutrition and growth in *Clarias* species. In view of the prospects for improved production characteristics of these species by genetic manipulation, genetic aspects of nutrition and growth are included.

NUTRITIONAL STUDIES

Natural feed

Ecological studies and studies in ponds (*e.g.* Bruton, 1979; Mbewaza-Ndawula, 1984; Uys, 1989) have shown that juvenile *C. gariepinus* feed in decreasing order of preference, on insects and crustaceans, molluscs, detritus and plankton. *C. batrachus* shows similar preferences (Mookerjee and Mazumdar, 1950). Subadults and adults feed mainly on fish. *C. gariepinus* can vary its food according to availability (Clay, 1979) and the species is thus considered an opportunistic omnivore. Their omnivorous nature was confirmed by Uys (1989), who found *C. gariepinus* to possess proteases similar to carnivorous species, starch digestive capabilities similar to those of specialized herbivores and lysozyme and alkaline phosphatase as in detritivores. The species is physiologically equipped to cope with infrequent and irregular meals, as its digestive enzymes respond faster than those of eel (*Anguilla anguilla*) or carp (*Cyprinus carpio*), to feeding (Uys *et al.*, 1987).

The natural or semi-natural food preferences and processing abilities are considered indicative of feed requirements and have been used as a basis for nutritional studies. It is plausible to assume that all *Clarias* species cultured to a large extent share the natural feeding habits described above for *C. gariepinus*.

Nutritional requirements

Commercial trout feeds have been used to study overall growth performance in *Clarias* species (*e.g.* Hogendoorn, 1981; Anderson and Fast, 1991). To elucidate dietary requirements for protein (%) and energy (as gross energy GE, digestible energy DE or metabolizable energy ME; in kJ/g) specific diets have been used. In general, protein requirements seem to be in the order of over 40% for *C. gariepinus* and somewhat lower for *C. batrachus* and *C. isheriensis*. Energy levels range from 13 to 17 kJ GE/g, resulting in protein-energy (P/E) ratios of between 31 and 36 mg/kJ GE and somewhat lower for *C. batrachus* and *C. isheriensis* (*table* 1). Evaluation criteria in *table* 1 are growth rate, feed conversion efficiency and protein utilization, with one exception (digestive enzyme activities; Singh and Singh, 1992). Unfortunately, energy requirements are not uniformly expressed (GE, DE or ME), hampering objective comparison. Nevertheless, species differences regarding these requirements appear to exist. Moreover, optimum P/E ratios depend on temperature, as was found for *C. gariepinus* (Henken *et al.*, 1986) (see below), and one P/E figure therefore does not necessarily suffice to describe requirements at a range of ambient temperatures.

Table 1. – Dietary protein and energy requirements.

Protein (%)	Energy[a] (kJ/g)	P/E[b] (mg/kJ)	Reference
Clarias gariepinus			
>40	13 ME	31	Machiels and Henken (1985)
40-42	14-16 DE	26-29	Uys (1989)
40	11-13 GE	31-36	Degani *et al.* (1989)
Clarias batrachus			
40	13-17 GE	23-31	Patra and Ray (1988)
40	16 GE	25	Khan and Jafri (1990)
40	–	–	Singh and Singh (1992)
30	–	–	Chuapoehuk (1987)
Clarias isheriensis			
37-40	13 ME	28-31	Fagbenro (1992*a*)

[a] GE = gross energy; DE = digestible energy; ME = metabolizable energy.

[b] P/E = protein-energy ratio.

– no data.

Fats or oils and carbohydrates are sources of non-protein energy. Uys (1989) varied fat percentages at a constant dietary protein level (42%) and arrived at an optimum fat percentage for *C. gariepinus* of 10-12%. In fact, most *Clarias* diets reported seem to have similar or slightly lower fat contents (*e.g.* *C. batrachus*, Patra and Ray, 1988; *C. gariepinus*, Heinsbroek *et al.*, 1989, Degani *et al.*, 1988, 1989; *C. isheriensis*, Fagbenro, 1992*a*).

Because of the limited possibilities, at least in *C. gariepinus*, to include high levels of fat (above 20%) due to the ensuing reduced feed intake (see below) or for reasons of local ingredient availability, carbohydrates are included in diets. Teleosts in general have a limited capacity to assimilate and metabolize carbohydrates (Cowey and Cho, 1993) and there is some controversy about the ability of *Clarias* species to utilize carbohydrates. The natural diet of especially juvenile *Clarias* may contain considerable amounts of carbohydrates (Uys, 1989) and studies on digestive enzyme activities point to a carbohydrate digesting capacity (see above). On the other hand, Bhatt (1980) found *C. batrachus* to possess a low glucose tolerance and Machiels and Van Dam (1987) mention that *C. gariepinus* has a low ability to metabolize glucose rapidly. Degani and Revach (1991) compared digestive capabilities of tilapia (*Oreochromis aureus* × *O. niloticus*), common carp (*Cyprinus carpio*) and *C. gariepinus*, and found the latter to have carbohydrate digestive capabilities lower than tilapia but higher than carp, whereas fat was digested better than by tilapia but less good than by carp. Despite the existing controversy, carbohydrate levels in *Clarias* diets are often substantial, and reportedly range from 15 to 35% in *C. gariepinus* (Balogun and Ologhobo, 1989; Heinsbroek *et al.*, 1990; Fagbenro *et al.*, 1993), from 20 to 66% in *C. batrachus* (Venkatesh *et al.*, 1986, Patra and Ray, 1988; Hasan and Jafri, 1989, Singh and Singh, 1992) and from 17 to 48% in *C. isheriensis* (Fagbenro, 1992*a*).

Feed ingredients

Clarias diets are usually made up of a variety of ingredients, to meet the compositional requirements discussed above. *Table* 2 mentions ingredients and their inclusion levels in what seem to be "standard" experimental diets for *C. gariepinus*, *C. batrachus* and *C. isheriensis* as encountered in literature. Vitamin and mineral additions have been omitted in this table, since they usually are added in the form of commercial premixes. Generally speaking, fish meal constitutes the main protein source (some 40-60%), relinquished only when a protein-rich alternative is included, mostly of vegetable origin (*e.g.* groundnut cake, soybean meal) (Chuapoehuk, 1987; Balogun and Ologhobo,1989; Fagbenro, 1992*b*).

GROWTH PERFORMANCE

Several studies have addressed the interplay of feeding level, body weight on temperature on growth performance of *Clarias* species. Bioenergetic studies in *C. gariepinus* revealed that the high ratio between metabolizable energy for production (ME_p) and that for maintenance (ME_m), and the high effiency of conversion of ME_p into retained energy, largely explain the highly efficient feed conversion of *C. gariepinus* (Hogendoorn, 1983). The ratio ME_p/ME_m varies with body weight and temperature, due to an interactive effect of feeding level and temperature on the weight exponents in the allometric relations of feed intake and metabolism with body weight. For example, in *C. gariepinus* ME_p/ME_m was calculated to be 2.8, 7.0 and 9.4 for 5 g fish and 3.7, 4.9 and 2.6 for 200 g fish, at 20, 25 and 30°C, respectively (Hogendoorn, 1983). In subsequent studies, ME_p/ME_m for *C. gariepinus* was calculated to range from 4 to 13, as compared to 2-4 in eel, 1-9 in rain- bow trout (*Oncorhynchus mykiss*) and 5 in grass

Table 2. – Ingredients in *Clarias* diets.

Animal origin							Vegetable origin												Ref.
FM	BM	PM	CM	FO	G	AF	WF	WS	WB	R	RB	C	CS	SM	GC	BW	M	VO	
C. gariepinus																			
45	8	–	–	4	–	–	10	–	–	–	–	–	10	20	–	–	–	–	1
43	–	–	10	3	–	–	18	–	–	–	–	18	–	–	–	–	8	–	2
40	–	20	–	–	–	–	–	–	40	–	–	–	–	–	–	–	–	–	3
40	8	–	–	–	–	–	–	–	–	–	15	20	–	–	13	–	–	–	4
23	–	–	–	–	–	–	–	–	–	–	–	–	–	–	45	5	–	5	5
C. batrachus																			
60	–	–	–	–	–	–	30	–	–	–	10	–	–	–	–	–	–	–	6
49	–	–	–	1	–	–	10	–	30	–	10	–	–	–	–	–	–	1	7
48	–	–	–	–	10	–	–	28	–	–	–	–	–	–	–	–	–	9	8
25	–	–	–	–	–	3	–	–	–	35	–	–	–	34	–	–	–	–	9
C. isheriensis																			
13	10	–	–	–	–	–	–	–	–	–	–	24	–	–	41	4	–	–	10

FM fish meal; BM blood meal; PM poultry meal; CM carcass meal; FO fish oil; G gelatin; AF animal fat; WF wheat flour; WS wheat starch; WB wheat bran; R rice (broken); RB rice bran; C corn (maize); CS corn starch; SM soybean meal; GC groundnut cake; BW brewery waste; M molasses powder; VO vegetable oil.

References: 1 Heinsbroek *et al.*, 1989, 2 Uys, 1989, 3 Degani *et al.*, 1988, 4 Fagbenro *et al.*, 1993, 5 Balogun and Ologhobo, 1989, 6 Venkatesh *et al.*, 1987, 7 Hasan *et al.*, 1989, 8 Singh and Singh, 1992, 9 Chuapoehuk, 1987, 10 Fagbenro, 1992*a,b*.

carp (*Ctenopharyngodon idella*). Hogendoorn (1983) calculated an efficiency of conversion of ME_p into retained energy of 0.8 in *C. gariepinus*, as compared to 0.7 in carp and rainbow trout. This efficiency in *C. gariepinus* is independent of body weight, feeding level and temperature, and these factors therefore affect growth mainly through maintenance requirements and maximum feed intake or metabolism (Heinsbroek, 1987). Henken *et al.* (1986) showed that optimum P/E ratios are also affected by temperature (25 mg/kJ ME at 24°C and 34.7 mg/kJ ME at 29°C). Other studies have confirmed the relationship between temperature and growth, in *C. gariepinus* (Degani *et al.*, 1989) and in *C. fuscus* (Anderson and Fast, 1991). Within the genus, species differences regarding optimum temperature for growth have been noted; Anderson and Fast (1991) state that juvenile *C. fuscus* have a lower temperature than *C. gariepinus*.

Machiels and Henken (1986) developed a dynamic simulation model to predict the relationship between feeding level and growth and metabolism of *C. gariepinus* of different weight classes at different temperatures and fed a commercial diet (see above), based upon nutrient intake, digestion, absorption, biochemical reactions in the intermediate metabolism and the ultimate deposition of body constituents. Body weight, body fat percentage, feed composition, feeding level and temperature were input values yielding growth, protein gain, fat gain and oxygen consumption as output values. The model adequately predicted the relationships mentioned above, and the authors concluded that *C. gariepinus* utilizes nutrients at maximum biochemical efficiency. In a subsequent study (Machiels and Henken, 1987), the effect of feed composition (protein, fat and carbohydrates) was incorporated. At high dietary fat levels (22% or more) fresh weight gain decreased, because of reduced intake, caused by a rapidly increasing body fat percentage. This had been observed earlier for *C. gariepinus* (Machiels and Henken, 1985) and led the authors to propose a feed intake regulation model based on body fat percentage. Machiels and Van Dam (1987) therefore proceeded to adapt the model to account for the effect of body composition, assuming maximum feed intake would be regulated by lipostatic and glucostatic mechanisms, the former at low dietary carbohydrate levels, the latter at high dietary carbohydrate levels. Using this model, fresh weight gain of *C. gariepinus* fed diets with different compositions, can be predicted.

Optimum recorded specific growth rate (SGR in % of body weight per day) and feed conversion (FC as g feed per g fish growth) have been compiled in *table* 3, for *C. gariepinus*, but also for *C. isheriensis*, *C. batrachus* and *C. fuscus* at optimum feeding levels. Since species differences regarding optimum temperature exist (see above), data in *table* 3 relate to optimum temperatures as stated by the authors. In *figure* 1 (relation between body weight and SGR and relation between body weight and FC), fitted curves for *C. gariepinus* data are given for comparison with ranges found in the other species (from *table* 3). In *C. gariepinus* SGR decreases from ca 12%/day in juveniles to less than 2%/day in adults (200-300 g). Although data from species other than *C. gariepinus* are limited, *figure* 1 indicates that *C. isheriensis*, *C. batrachus* and *C. fuscus* all perform less than *C. gariepinus* (*fig.* 1*a*). Similarly, in *C. gariepinus* FC increases from 0.7 in juveniles to *ca.* 1.5 in adults, and again *C. isheriensis*, *C. batrachus* and *C. fuscus* perform less (*fig.* 1*b*). At face value, these data support the popularity of *C. gariepinus* as compared to other species of the genus, for aquaculture (see above).

Table 3. – Specific growth rate (SGR) and feed conversion (FC) at optmimum feeding levels (FL) and temperatures (Temp.) for different size ranges of *Clarias* species.

Size range (g)	SGR (%/day)	FC (g/g)	FL (%/day)	Temp. (°C)	Ref.
Clarias gariepinus					
0.3-3	11	1.2	10	30	1
0.5-10	8-12	0.7-1.4	10	30	2
1-14	9-12	0.6-0.9	–	26-34	3
3.5-21.5	1.7	0.94	4	27	4
9-36	5-7	0.8-1.0	–	26-34	3
5-40	6	1.6	5	30	1
17-49	3-5	0.7-1.0	–	26-34	3
25-70	4	1.6	4	30	1
5-150	3.7	–	ad lib.	–	5
5-170	3.9	–	ad lib.	–	5
95-200	2	3.0	1.5	25	1
5-220	4.2	–	ad lib.	–	5
160-303	1.3-3.1	1.17-2.01	–	26-34	3
5-320	4.5	–	ad lib.	–	5
10-340	1.90	0.93	4	27	6
Clarias isheriensis					
30-120	2.1-2.2	1.7	5	27	7
12-325	1.8	1.9	ad lib.	29	8
Clarias batrachus					
0.1-9	7.5	1.3	10	–	9
10	0.9	1.2	5	30	10
20-40	1.8	1.2	3	30	11
20-160	1.7	3.4	8	24-28	12
Clarias fuscus					
1-60	2.5-4.9	1.2-1.8	2-6	25	13
60-160	0.6-0.8	2.4-6.8	2-6	25	13
140-260	0.2-0.4	2.8-11.0	1-3	25	13

– no data.

References: 1 Hogendoorn *et al.*, 1983, 2 Hogendoorn, 1981, 3 Uys, 1989, 4 Degani *et al.*, 1988, 5 Wedekind, 1991, 6 Degani *et al.*, 1989, 7 Fagbenro, 1992*a*, 8 Fagbenro, 1993, 9 Chuapoehuk, 1987, 10 Patra and Ray, 1988, 11 Hasan and Jafri, 1994, 12 Venkatesh *et al.*, 1986, 13 Anderson and Fast, 1991.

GENETIC ASPECTS OF NUTRITION AND GROWTH

Male *C. gariepinus* have been observed to grow faster than females (*e.g.* Christensen, 1981; Henken

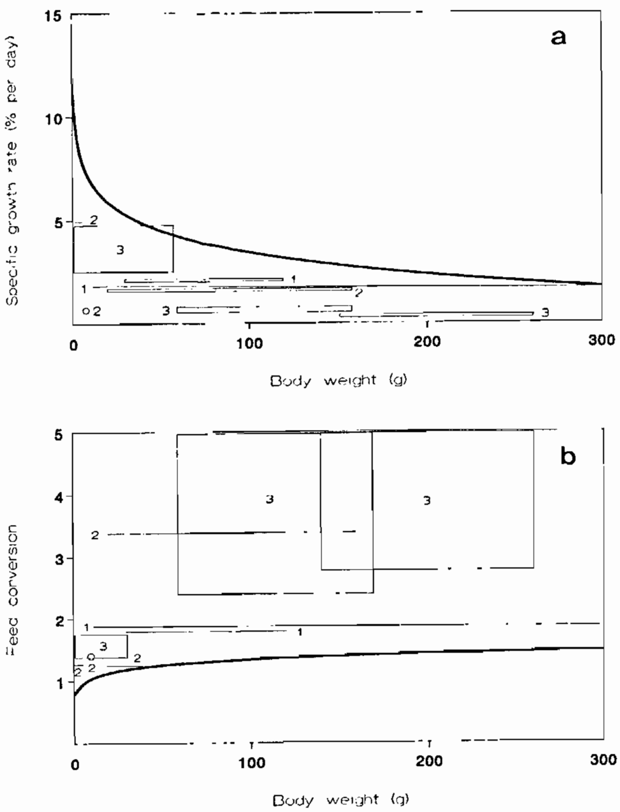

Figure 1. – Relationship of body weight of *C. gariepinus* (curve), *C. isheriensis* (1), *C. batrachus* (2) and *C. fuscus* (3) with specific growth rate (a) and feed conversion. (b) – Data from *table* 3.

et al., 1987*a*; Wedekind, 1991). They also have a better feed conversion, a lower fat and energy deposition and a higher gutted weight than females (96% vs. 93%) (Henken *et al.*, 1987*a*).

Triploidy in *C. gariepinus* offers no advantages in terms of growth rate or feed conversion, although diploids have a higher gutted weight (because of smaller gonads) and deposit more fat and less protein (Henken *et al.*, 1987*b*). Similar results were obtained with *C. batrachus* (Rustidja *et al.*, 1993). The decision to culture triploids should therefore be based on expected advantages concerning body composition and gutted weight.

To benefit from possible hybrid vigor and sterility or monosexuality enhancing growth and feed utilization, hybrids of *Clarias* species have been studied. Legendre *et al.* (1992) compared *C. gariepinus* and *Heterobranchus longifilis* with their reciprocal hybrids. *C. gariepinus* had lower growth rates and a younger age at maturity (1.7% and 5-6 months) than *H. longifilis* (1.9% and 10 months) or either cross (1.9% and 1.8%; both 10 months). These results indicate that hybridization has potential for increasing growth performance.

For genetic selection programs to focus on, growth performance and late maturation are obvious characteristics, although the latter may be less relevant for *C. gariepinus* in the Netherlands, where market weight in commercial culture (800-900 g; Verreth and Eding, 1983) is usually reached before gonads have fully developed. Variation in the desired trait has to be demonstrated for selection to give results. Prinsloo *et al.* (1988) showed slightly superior growth of a black strain over that of a red strain of *C. gariepinus*. Wedekind (1991) demonstrated differences regarding growth and body composition between strains of *C. gariepinus*. Also findings of Grobler *et al.* (1992) suggest feasibility of genetic selection for growth in *C. gariepinus*.

Selection for rapid growth as such may have disadvantages, since the level of aggression in fish may concurrently increase (Ruzzante, 1994). Furthermore, growth is a complex phenomenon and the process to adress in order to improve growth, should be identified. *C. gariepinus* utilizes feed nutrients at maximum biochemical efficiency (Machiels and Henken, 1986; see above), rendering selection for higher feed utilization efficiencies redundant. Rather, selection should focus on *e.g.* lower maintenance requirements (Machiels and Henken, 1986) or increasing the ability to metabolize glucose (Machiels and Van Dam, 1987).

CONCLUSION

The superior performance of *C. gariepinus* compared to other *Clarias* species in terms of growth rate and feed has probably contributed to fact that *C. gariepinus* has been widely introduced to areas outside its natural range (Verreth *et al.*, 1993). Since *C. gariepinus* appears to operate at maximum biochemical efficiencies (Machiels and Henken, 1986), environmental factors influence growth through maintenance requirements and maximum feed intake and metabolizability. To futher improve performance of *C. gariepinus* maintenance requirements could be lowered, through selection or through improvement of husbandry systems (*e.g.* reduction of stress or improvement of water quality). Maximum feed intake could be addressed, *e.g.* by fine tuning feed composition to age or size of the fish, since body composition regulates feed intake (Machiels and Henken, 1987; Machiels and Van Dam, 1987) and body composition changes with age/size (Hogendoorn, 1983).

Monosex culture or triploidy does not seem to hold much future, unless composition of meat and dressing percentages are considered important criteria (Henken *et al.*, 1987*a,b*; Rustidja *et al.*, 1993). In contrast, hybridization of *Clarias* species has potential (*e.g.* Legendre *et al.*, 1992).

Selection programs seem to be still in the phase of assessing phenotypic diversity and genetic variation (*e.g.* Grobler *et al.*, 1992) but may hold great future if feasible traits are selected for in homozygous individuals from which isogenic strains are established. To this end, genome manipulation techniques (androgenesis, gynogenesis) currently under investigation in our laboratory will facilitate production of homozygous individuals, from which superior specimens can be cross bred to yield isogenic strains with better performance characteristics.

REFERENCES

Anderson M. J., A. W. Fast 1991. Temperature and feed rate effects on Chinese catfish, *Clarias fuscus* (Lacépède). *Aquac. Fish. Manage.* **22**, 435-441.

Arecrat S. 1987. *Clarias* culture in Thailand. *Aquaculture* **63**, 355-362.

Balogun A.M., A.D. Ologhobo 1989. Growth performance and nutrient utilization of fingerling *Clarias gariepinus* (Burchell) fed raw and cooked soybean diets. *Aquaculture* **76**, 119-126.

Bhatt S. D. 1980. Effect of glucose loading on the glycogen content in some tissues of *Clarias batrachus* (L.). *J. Anim. Morphol. Physiol.* **27**, 267-272.

Bruton M. N. 1979. The food and feeding behaviour of *Clarias gariepinus* (Pisces; Clariidae) in Lake Sibaya, South Africa, with emphasis on its role as a predator of cichlids. *Trans. Zool. Soc. London.* **35**, 47-114.

Christensen M. S. 1981. A note on the breeding and growth rates of the catfish *Clarias gariepinus* in Kenya. *Aquaculture* **25**, 285-288.

Chuapochuk W. 1987. Protein requirements of walking catfish, *Clarias batrachus* (Linnaeus), fry. *Aquaculture* **63**, 215-219.

Clay D. 1979. Population biology, growth and feeding of African catfish (*Clarias gariepinus*) with special reference to juveniles and their importance in fish culture. *Arch. Hydrobiol.* **87**, 453-482.

Cowey C. B., C. Y. Cho 1993. Nutritional requirements of fish. *Proc. Nutr. Soc.* **52**, 417-426.

Degani G., Y. Ben-Zvi, D. Levanon 1988. The effect of different dietary protein sources and temperatures on growth and feed utilization of African catfish *Clarias gariepinus* (Burchell). *Isr. J. Aquac.* **40**, 113-117.

Degani G., Y. Ben-Zvi, D. Levanon 1989. The effect of different protein levels and temperatures on feed utilization, growth and body composition of *Clarias gariepinus* (Burchell, 1822). *Aquaculture* **76**, 293-301.

Degani G., A. Revach 1991. Digestive capabilities of three commensal fish species: carp, *Cyprinus carpio* L., tilapia, *Oreochromis aureus* × *Oreochromis niloticus*, and African catfish, *Clarias gariepinus* (Burchell, 1822). *Aquac. Fish. Manage.* **22**, 397-403.

Fagbenro O. A. 1992*a*. Quantitative dietary protein requirements of *Clarias isheriensis* (Sydenham, 1980) (Clariidae) fingerlings. *J. Appl. Ichthyol.* **8**, 164-169.

Fagbenro O. A. 1992*b*. Utilization of cocoa-pod husk in low-cost diets by the clariid catfish, *Clarias isheriensis*. *Aquac. Fish. Manag.* **23**, 175-182.

Fagbenro O. A., D. H. J. Sydenham 1990. Studies on the use of *Clarias isheriensis* Sydenham (Clariidae) as a predator in *Tilapia guineensis* Dumeril (Cichlidae) ponds. *J. Appl. Ichthyol.* **6**, 99-106.

Fagbenro O. A., B. Balogun, N. Ibironke, F. Fasina 1993. Nutritional values of some amphibian meals in diets for *Clarias gariepinus* (Burchell, 1822) (Siluriformes: Clariidae). *J. Aquac. Trop.* **8**, 95-101.

Grobler J. P., H. H. Du Preez, F. H. Van Der Bank 1992. A comparison of growth performance and genetic traits between four selected groups of African catfish (*Clarias gariepinus* Burchell, 1822). *Comp. Biochem. Physiol.* **102A**, 373-377.

Hasan M. A., A. K. Jafri 1994. Optimum feeding rate, and energy and protein maintenance requirements of young *Clarias batrachus* (L.), a cultivable catfish species. *Aquac. Fish. Manag.* **25**, 427-438.

Hasan M. A., M. G. M. Alam, M. A. Islam 1989. Evaluation of some indigenous ingredients as dietary protein sources for catfish (*Clarias batrachus*, Linnaeus) fry. In: Aquacultural Research in Asia: Management Techniques and Nutrition, E. A. Huisman, N. Zonneveld, A. H. M. Bouwmans, eds., Wageningen, Pudoc, 125-137.

Haylor G. S. 1993. Aspects of the biology and culture of the African catfish *Clarias gariepinus* (Burchell, 1822) with particular reference to developing African countries. In: Recent Advances in Aquaculture IV, J.F. Muir, R. J. Roberts eds. Blackwell, 235-294.

Hecht T., W. Uys, P. J. Britz, eds. 1988. The culture of sharptooth catfish, *Clarias gariepinus*, in southern Africa. South African National Scientific Programmes Rep. 153, 133 p.

Heinsbroek L. T. N. 1987. Effects of body weight, feeding level and temperature on energy metabolism and growth in fish. In: Energy metabolism of farm animals. Effects of housing, stress and disease, Verstegen M. W. A., A. M. Henken, eds. Martinus Nijhoff, Dordrecht, Boston, Lancaster, 478-500.

Heinsbroek L. T. N., R. M. H. Van Thoor, L. J. Elizondo 1990. The effect of feeding level on the apparent digestibilities of nutrients and energy of a reference diet for the European eel, *Anguilla anguilla* L. and the African catfish, *Clarias gariepinus* (Burchell). In: The Current Status of Fish Nutrition in Aquaculture. Proc. Third Int. Symp. on Feeding and Nutrition in Fish., Aug. 28-Sept. 1, Toba, Japan, 1989, Takeda M., T. Watanabe eds. 175-188.

Henken A. M., M. A. M. Machiels, W. Dekker, H. Hogendoorn 1986. The effect of dietary protein and energy content on growth rate and feed utilization of the African catfish *Clarias gariepinus* (Burchell, 1822). *Aquaculture* **58**, 55-74.

Henken A. M., J. H. Boon, B. C. Cattel, H. W. J. Lobée 1987*a*. Differences in growth rate and feed utilization between male and female African catfish, *Clarias gariepinus* (Burchell, 1822). *Aquaculture* **63**, 221-232.

Henken A. M., A. M. Brunink, C. J. J. Richter 1987*b*. Differences in growth rate and feed utilization between diploid and triploid African catfish, *Clarias gariepinus* (Burchell, 1822). *Aquaculture* **63**, 233-242.

Hogendoorn H. 1981. Controlled propagation of the African catfish, *Clarias lazera* (C. and V.) IV. Effect of feeding regime in fingerling culture. *Aquaculture* **24**, 123-131.

Hogendoorn H. 1983. Growth and production of the African catfish, *Clarias lazera* (C. and V.) III. Bioenergetic relations of body weight and feeding level. *Aquaculture* **35**, 1-17.

Hogendoorn H., J. A. J. Jansen, W. J. Koops, M. A. M. Machiels, P. H. Van Ewijk 1983. Growth and production of the African catfish, *Clarias lazera* (C. and V.). II.

Effects of body weight, temperature and feeding level in intensive tank culture. *Aquaculture* **34**, 265-285.

Huisman E. A., C. J. J. Richter 1987. Reproduction, growth, health control and aquacultural potential of the African catfish, *Clarias gariepinus* (Burchell, 1822). *Aquaculture* **63**, 1-14.

Khan M. A., A. K. Jafri 1990. On the dietary protein requirement of *Clarias batrachus* Linnaeus. *J. Aquac. Trop.* **5**, 191-198.

Legendre M., G. G. Teugels, C. Cauty, B. Jalabert 1992. A comparative study on morphology, growth rate and reproduction of *Clarias gariepinus* (Burchell, 1822), *Heterobranchus longifilis* Valenciennes, 1840, and their reciprocal hybrids (Pisces, Clariidae). *J. Fish Biol.* **40**, 59-79.

Machiels M. A. M., A. M. Henken 1985. Growth rate, feed utilization and energy metabolism of the African catfish, *Clarias gariepinus* (Burchell, 1822), as affected by dietary protein and energy content. *Aquaculture* **44**, 271-284.

Machiels M. A. M., A. M. Henken 1986. A dynamic simulation model for growth of the African catfish, *Clarias gariepinus* (Burchell, 1822) I. Effect of feeding level on growth and energy metabolism. *Aquaculture* **56**, 29-52.

Machiels M. A. M., A. M. Henken 1987. A dynamic simulation model for growth of the African catfish, *Clarias gariepinus* (Burchell, 1822) II. Effect of feed composition on growth and energy metabolism. *Aquaculture* **60**, 33-53.

Machiels M. A. M., A. A. Van Dam 1987. A dynamic simulation model for growth of the African catfish, *Clarias gariepinus* (Burchell, 1822) III. The effect of body composition on growth and feed intake. *Aquaculture* **60**, 55-71.

Mbewaza-Ndawula L. 1984. Food and feeding habits of *Clarias mossambicus* from four areas in the lake Victoria basin, East Africa. *Environ. Biol. Fishes.* **10**, 69-76.

Mookerjee H. K., S. R. Mazumdar 1950. Some aspects of the life history of *Clarias batrachus* (Linn.). *Proc. Zool. Soc. Bengal* **3**, 71-79.

Patra B. C., A. K. Ray 1988. Performance of the air-breathing fish, *Clarias batrachus* (Linn.) at variable dietary protein levels. *Indian J. Anim. Sci.* **58**, 882-886.

Prinsloo J. F., H. J. Schoonbee, I. H. Van Der Walt 1989. Production studies with red and normal varieties of the sharptooth catfish *Clarias gariepinus* (Burchell) using a mixture of minced fish, bakery floor sweepings and a formulated pelleted diet. *Water S.A.* **15**, 185-190.

Rustidja, M. Sukkel, C. J. J. Richter, Kusman Sumawidjaja, E. A. Huisman 1993. Triploidy and growth performance in the Asian catfish, *Clarias batrachus* L. In: Genetics in Aquaculture and Fisheries Management. AADCP Workshop Proc., 31st August-4th September 1992, Univ. Stirling, Scotland, D. Penman, N. Roongratri, B. McAndrew eds. 145-150.

Ruzzante D.E. 1994. Domestication effects on aggressive and schooling behavior in fish. *Aquaculture* **120**, 1-24.

Singh R., R. P. Singh 1992. Effect of different levels of protein on the absorption efficiency in siluroid catfish *Clarias batrachus* (Linn.). *Isr. J. Aquac.* **44**, 3-6.

Uys W. 1989. Aspects of the nutritional physiology and dietary requirements of juvenile and adult sharptooth catfish, *Clarias gariepinus* (Pisces: Clariidae). PhD Thesis, Rhodes University, South Africa, 190 p.

Uys W., T. Hecht, M. Walters 1987. Changes in digestive enzyme activities of *Clarias gariepinus* (Pisces: Clariidae) after feeding. *Aquaculture* 63, 243-250.

Venkatesh B., A. P. Mukherji, P. K. Mukhopadhyay, P. V. Dehadrai 1986. Growth and metabolism of the catfish *Clarias batrachus* (Linn.) fed with different experimental diets. *Proc. Indian Acad. Sci. (Anim. Sci).* **95**, 457-462.

Verreth J. A. J., E. H. Eding 1993. European farming industry of African catfish (*Clarias gariepinus*): facts and figures. *Aquac. Europe.* **18**, 6-13.

Verreth J. A. J., E. H. Eding, G. R. M. Rao, F. Huskens, H. Segner 1993. A review of feeding practices, growth and nutritional physiology in larvae of the catfishes *Clarias gariepinus* and *Clarias batrachus*. *J. World Aquac. Soc.* **24**, 135-144.

Wedekind H. 1991. Untersuchungen zur Produktqualität Afrikanische Welse (*Clarias gariepinus*) in Abhängigkeit von genetischer Herkunft, Fütterung, Geschlecht und Schlachtalter. PhD Thesis, Georg-August University, Germany, 176 p. (In German with English summary).

Zheng W., J. Pan, W. Liu 1988. Culture of catfish in China. *Aquaculture* **75**, 35-44.