Nutritive Value of Gelatinized Corn Meal as a Carbohydrate Source to Grass Carp and Hybrid Tilapia *Oreochromis niloticus* × *O. aureus*

Toshio Takeuchi, Martha Hernández, and Takeshi Watanabe

Department of Aquatic Biosciences, Tokyo University of Fisheries, Konan, Minato, Tokyo 108, Japan

(Received February 9, 1994)

The effect of extrusion on the nutritional value of corn meal for grass carp *Ctenopharyngodon idella* and hybrid tilapia *Oreochromis niloticus* × *O. aureus* fingerlings was studied. Raw and extruded corn meal were mixed in five proportions at a 50% level in the diet, with a gelatinized ratio (GR) ranging from 29 to 100%.

The apparent starch digestibilities improved gradually by increasing the GR level. The energy digestibility was slightly improved in grass carp, while it was almost constant in tilapia. The percent gain, feed efficiency and protein efficiency ratio improved smoothly by increasing the GR level. However, the feed efficiency was still high (114% for grass carp and 119% for tilapia) even in the fish fed on a diet with raw corn meal. In tilapia, the daily feed consumption was not related to the GR. In the whole body composition, an increase of lipid content was observed with an increase of GR.

A gradual increase in gelatinization thus improves gradually the nutritive value of corn meal for grass carp and tilapia. However, the effect is not so strong. Both species are good at utilizing corn meal, even in its raw form and at a high concentration, particularly tilapia.

Key words: grass carp, tilapia, nutrition, digestibility, corn, extrusion, carbohydrates

Fish are known to be poor at using carbohydrates, and are considered potentially diabetic compared to human.^{1,2)} The optimum dietary levels of dextrin or extruded starch for efficient growth of fish are much lower than for omnivorous mammals³⁾ and carnivorous fish are less able to metabolize carbohydrates than omnivorous or herbivorous species.^{1,4)}

Carbohydrates are not essential nutrients for fish. However, being an abundant and inexpensive energy source, it is important to find out the maximum level and best physical form of carbohydrate that can be included in the diets in order to encourage efficient growth and reduce the cost of protein diets.

Starch is the main carbohydrate used in fish feed. The physical structure of the glucose chains is of particular interest because it has been found to affect greatly the nutritive value of the starch. The difference in nutritive value between the raw (β -starch)* and gelatinized form (α -starch)* has been extensively studied in the carnivorous rainbow trout *Oncorhynchus mykiss*^{5–12)} and to a lesser extent in other species like common carp *Cyprinus carpio*,^{7,13–15)} red sea bream *Pagrus major*,^{14,16)} Siberian sturgeon *Acipenser baeri*,¹⁷⁾ striped jack *Caranx delicatissimus*,¹⁸⁾ and yellowtail *Seriola quinqueradiata*.¹⁸⁾ Those studies showed that the increase in starch gelatinization of different plant sources had the following effects:

1. Improvement in apparent digestibility of starch and energy.
2. Improvement in feed efficiency (FE) and protein efficiency ratio (PER).
3. Decrease in the relative feed consumption, if fed to

satiation.

4. Increase in whole body lipid content.

Besides common carp, the species already studied are at least semi-carnivorous. The purpose of this study was to observe the effect of extrusion on the nutritional value of starch in two freshwater non-carnivorous species, grass carp *Ctenopharyngodon idella* and hybrid tilapia *Oreochromis niloticus* × *O. aureus*. Corn meal, a widely used product, was chosen as the starch source, and the above effects were studied in order to make qualitative interspecific comparisons.

Materials and Methods

Experimental Design

Feeding experiments were conducted with fingerlings of grass carp and tilapia weighing 4.0 and 4.5 g on average, respectively. Fish were distributed randomly in aquarium tanks with aeration, at a density of 20 fish/tank for grass carp and 25 fish/tank for tilapia. For each treatment, duplicate tanks were used. Rearing and feeding conditions are shown in Table 1. The

Table 1. Rearing and feeding conditions

	Grass carp	Tilapia
Prefeeding period	20 days	12 days
Feeding period	52 days	54 days
Feeding per day	3 (9:30, 13:30, 17:30)	3 (9:30, 13:30, 17:30)
Feeding amount	Restricted, 2.4% BW	To satiation
Tank volume	40 l	70 l
Water fluid	250–350 ml/min	250–350 ml/min
Temperature	25 ± 1°C	23 ± 1.5°C

* Raw and gelatinized starch are respectively designated as β - and α -starch in Japan.

conditions were set as similar as possible between both species to allow comparison of results. Grass carp are very nervous fish, so the feeding amount was restricted because of the difficulty of determining the satiation point. The restricted amount (2.4% of body weight) was set as high as possible and determined by observation. A prefeeding period of 20 days for grass carp and 12 days for tilapia was necessary for the fish to adapt to a casein diet.

At the beginning and the end of the feeding period the fish were anesthetized with ethyl aminobenzoate (100 ppm) and were weighed individually. In the case of grass carp, the fish were weighed every two weeks to adjust the feeding amount.

Corn meal purchased from Nippon Formula Feed MFG was extruded using a small type of twin extruder (Alfalyzer α -100, Suehiro iron foundry). The extrusion conditions for gelatinization of corn meal were as follows: screw speed 396 rpm; feed rate 100 kg/h; water volume 13.2 kg/h; steam volume 8 kg/h; barrel temperature 100°C; material temperature, die 120–125°C, middle 100°C, back 96°C, and pressure 59–65 bars. The composition of the corn meal is listed in Table 2.

Table 2. Gelatinized ratio and proximate composition of corn meal

	Extruded	Raw
Gelatinized ratio	99	23
Moisture	10.0	10.6
Crude protein	8.7	8.7
Crude lipid	3.0	4.2
Crude starch	75.5	73.6
Crude ash	1.3	1.3

Table 3. Composition of the experimental diets (%)

Ingredients	Diet number				
	1	2	3	4	5
Raw corn meal	50	37.5	25	12.5	0
Ext. corn meal	0	12.5	25	37.5	50
Casein	32.5	32.5	32.5	32.5	32.5
Soybean oil	3	3	3	3	3
Pollock liver oil	2	2	2	2	2
Cellulose	0	0	5	5	5
CMC* ¹	5	5	0	0	0
Others* ²	7.5	7.5	7.5	7.5	7.5

Nutrient content (grass carp)

Gelatinized ratio (GR)	30	45	74	88	100
Moisture	6.1	5.0	5.2	6.1	6.9
Crude protein	35.1	35.5	35.4	34.1	33.0
Crude lipid	6.6	6.6	6.8	6.8	6.8
Crude starch	40.0	40.3	38.3	38.8	40.0
Crude ash	5.7	5.7	5.4	5.3	5.3
Gross energy* ³	474	481	483	475	475
Digestible energy* ³	373	380	401	404	412

Nutrient content (tilapia)

Gelatinized ratio (GR)	29	48	71	90	100
Moisture	5.3	4.8	5.1	4.2	6.3
Crude protein	36.3	36.3	36.7	36.7	35.0
Crude lipid	6.3	6.4	6.4	6.6	6.4
Crude starch	38.6	39.8	38.0	38.1	39.3
Crude ash	5.7	5.6	5.1	5.2	5.2
Gross energy* ³	479	477	480	483	478
Digestible energy* ³	421	422	424	428	427

*¹ Carboxymethyl cellulose.

*² Mineral mixture,²⁸⁾ 5; vitamin mixture,²⁹⁾ 1; choline chloride, 0.4; vitamin E (50% pure), 0.1; chromic oxide (chromic oxide : cellulose, 1 : 1), 1.

*³ kcal/100 g.

The experimental diets were the same for both species and their compositions are listed in Table 3. The diets were prepared separately for each species; therefore, the nutrient content was slightly different. Diet 3 was used for prefeeding. To adjust the gelatinized ratio (GR), raw and extruded corn meal were mixed in five different proportions at a 50% level in the diets. The level of starch in the diets was almost 40%. Except cellulose and carboxymethyl cellulose (CMC), the rest of the ingredients were included at the same level in all diets and were formulated to satisfy the nutritional requirements of these species.^{19,20)} Casein was used as a protein source. In diets 1 and 2, cellulose was replaced by CMC as a binder because raw corn meal has no binding properties. Chromic oxide was included in the diets to measure the apparent digestibility. The experimental diets were fed in a dry pellet form.

Fish were collected for whole body analysis, 15 at the beginning and 12 from each tank at the end of the experiment. They were homogenized and chemically analyzed on a wet basis. Feces were collected during the last two weeks of the feeding period using the TUF method described by Satoh *et al.*²¹⁾

Analytical Methods

Corn meal was analyzed for proximate composition and diets for proximate composition, chromic oxide, gross energy, and GR. Dried feces were analyzed for proximate composition and chromic oxide. Whole body (fish carcass) was also analyzed for proximate composition. All chemical analyses involved two determinations.

Moisture content was determined by desiccation at 105°C until reaching constant weight and ash content by incineration in a muffle furnace at 550°C. Crude protein (N $\times$ 6.25) was determined using a Kjel-Auto (Mitamura Riken Kogyo Inc. VS-KT.P) after acid digestion. For crude lipid and crude starch analyses the Folch and Somogyi-Nelson methods were used respectively. Gross energy was determined directly with a bomb calorimeter (Shimadzu CA-4P). Chromic oxide content was measured by the method of Furukawa and Tsukahara.²²⁾

The gelatinized ratio (GR) was determined by the diastase method,²³⁾ and the general procedure and calculation have been described previously.⁷⁾ This method is based on the different degradability of raw and gelatinized starch to the diastase enzyme. Because of the physical structure of the glucose chains in raw starch, the enzyme cannot digest them easily and the GR values are usually low. When starch is gelatinized by extrusion or other processes, the enzyme can achieve digestion, leading to high GR values.

The apparent digestibilities of protein, lipid, starch, and energy were calculated by the formula presented in Hepher.²⁴⁾

Statistical Analyses

The means of the final body weight of the duplicates for each treatment were compared using the single-factor analysis of variance at a significance level of $p < 0.05$, but no differences were found for any of the five sets of duplicates. They were therefore aggregated and analyzed as a unit.

After the previous comparison, the five experimental groups were analyzed using Duncan's multiple range test to compare the means of the final body weight at a significance level of $p < 0.05$.

Results and Discussion

In our discussion, all the results were analyzed in terms of their relationship to the GR of the diets.

Apparent Digestibilities

The apparent digestibilities in grass carp and tilapia are shown in Table 4 and Fig. 1. The GR of the different diets ranged between 29 and 100%. The GR of the diets containing raw corn meal alone was not so low because the GR of starch in raw corn meal was 23%. In both species the protein and lipid digestibilities were not influenced by GR level. In the case of starch digestibility, there was a gradual improvement with an increase in GR, this tendency being stronger in grass carp. The starch digestibility of the diet with raw corn meal was not so low (63%) in grass carp and was still high (79%) in tilapia. The inclusion of 5% CMC in diets 1 and 2 seemed not to affect the starch

Table 4. Apparent digestibility of dietary nutrients

GR (%)*	Grass carp					Tilapia				
	30	45	74	88	100	29	48	71	90	100
Protein	95.2	95.5	95.9	96.6	96.5	97.9	98.0	98.5	98.5	98.4
Lipid	87.7	88.3	91.6	91.8	92.2	97.1	97.4	97.6	97.6	97.8
Starch	63.0	65.8	78.3	83.9	89.9	79.1	82.7	87.2	88.4	91.7
Energy	78.6	78.9	83.0	85.1	86.8	87.8	88.5	88.3	88.7	89.3

* Gelatinized ratio.

Fig. 1. Relationship between dietary gelatinized ratio and apparent digestibility of nutrients.

Table 5. Results of a 52-day feeding trial with grass carp and a 54-day feeding trial with tilapia

GR (%)	Grass carp					Tilapia				
	30	45	74	88	100	29	48	71	90	100
Average body weight (g)* ¹										
Initial	4.00	3.99	3.98	4.01	4.02	4.46	4.43	4.47	4.46	4.55
	±0.5	±0.6	±0.5	±0.5	±0.4	±0.6	±0.5	±0.5	±0.6	±0.5
Final	24.7	24.9	25.8	26.9	27.3	35.6	34.7	39.4	38.9	40.9
	±6.1	±9.1	±9.3	±9.0	±8.2	±13.0	±11.0	±15.0	±11.0	±9.3
Percent gain	519	525	549	572	579	700	682	782	772	799
FE (%)** ²	114	119	118	120	120	119	122	123	128	129
PER** ³	3.3	3.4	3.3	3.5	3.6	3.3	3.4	3.4	3.5	3.7
DEI (kcal)** ⁴	9.1	8.9	9.6	9.6	9.8	10.2	9.9	10.1	9.9	9.8
DFC** ⁵	2.4	2.3	2.4	2.4	2.4	2.4	2.3	2.4	2.3	2.3

*¹ Mean ± standard deviation (Grass carp: *n* = 20, hybrid tilapia: *n* = 25, both in duplicate).*² Feed efficiency {(g gain/g feed) × 100}.*³ Protein efficiency ratio.*⁴ Digestible energy intake/day/100 g fish.*⁵ Daily feed consumption (% body weight).

digestibility. The energy digestibility differed between the two species: it slightly improved with an increase in GR in grass carp while it was almost constant in tilapia. This might be explained by the contribution of gelatinized starch to digestible energy. In tilapia, the starch digestibility was not so markedly affected by GR, having less influence on the energy digestibility. In general, the digestibilities of the nutrients were higher in tilapia than in grass carp.

As described above, improvement of starch digestibility by gelatinization has been reported for various species and

with different sources of starch.^{5-9,13-15)} The same improvement was observed in grass carp and tilapia, and the degree of extrusion in terms of GR positively influenced the digestibility of starch.

Growth, Feed Efficiency, and Other Parameters

The results of the feeding trials with grass carp and tilapia are shown in Table 5 and Fig. 2.

In grass carp there was a difference in final body weight ranging from 24.7 to 27.3 g, but there was statistically no

Fig. 2. Relationship between dietary gelatinized ratio and percent gain and feed efficiency.

Table 6. Proximate composition of the whole body

GR (%)*	Grass carp						Tilapia					
	Initial	30	45	74	88	100	Initial	29	48	71	90	100
Moisture	79.4	77.5	77.1	76.0	75.7	74.8	75.9	73.0	72.5	71.6	71.1	70.8
Crude protein	12.4	13.1	12.8	13.1	13.1	13.3	14.8	15.5	15.7	15.7	15.7	15.7
Crude lipid	5.8	6.7	6.9	7.9	8.1	8.6	5.1	7.5	8.4	8.6	9.2	9.4
Crude ash	2.2	2.4	2.3	2.4	2.5	2.5	3.7	2.9	3.0	3.0	3.3	3.3

* Gelatinized ratio.

significant difference between any of the groups ($p > 0.05$). There was a gradual improvement in percent gain (519 to 579), FE (114 to 120%), and PER (3.3 to 3.6) with an increase in GR. The high value for FE obtained at a GR of 45% might be due in part to the slightly lower daily feed consumption (DFC) of the group. The FE for the diet with raw corn meal was still high (114%). The growth performance of grass carp showed that the increase in the level of gelatinization gradually improves the nutritive value of the diets. These results agree completely with the values obtained for starch digestibility.

The results in tilapia showed the same tendency as those in grass carp. The final body weight ranged from 34.7 to 40.9 g, but the statistical analyses showed no significant difference between the groups ($p > 0.05$). There was a gradual increase in percent gain (700 to 799), FE (199 to 129%), and PER (3.3 to 3.7) with an increase in GR. The FE for the diet prepared with raw corn meal was still high (119%). As described for grass carp, the gradual increase in the level of gelatinization slightly improved the nutritive value of the diets corresponding to the increase of starch digestibility. The DFC of tilapia was very similar for all diets and was not influenced by an increase in GR, differing from reported results for other species^{8-10,15,16,18}) when fed to satiation. As expected, the digestible energy intake (DEI) was also similar among all treatments. This might be explained by the fact that the DE content of the diets was also very similar and that fish normally eat to satisfy their energy requirements.

These two species seemed to respond to gelatinization of starch in terms of FE and PER in a similar way to other studied species.^{7-11,15-18})

Body Composition

Proximate composition of the whole body of grass carp

and tilapia is listed in Table 6. As described earlier, gelatinization of starch results in an increase of body lipid content in various species.^{7,8,15,16,18}) Here again both species showed a gradual increase in whole body lipid content with an increase in GR. Protein content was not affected by GR and moisture was reduced, probably reflecting the increase of lipid.

From this study it can be concluded that the extrusion process in terms of increase in GR improves the nutritive value of corn meal for grass carp and tilapia. The effect of extrusion in this study corresponded broadly to previous results with other species in terms of starch digestibility, growth performance and body composition.

It is difficult to define an appropriate level of GR for practical diets for these species. They can use corn meal efficiently even in its raw form and at a high level of inclusion. Therefore, whether to use the gelatinization process depends on the cost of extrusion compared to the improvement of growth performance.

Although no information is available on the effect of extrusion on the nutritive value of starch in the studied species, other experiments are related to this work. In an experiment with grass carp, Law²⁵) reported a digestion coefficient of 88% for carbohydrate of corn meal. Anderson *et al.*²⁶) compared the effect of different carbohydrates at various proportions on tilapia *Oreochromis niloticus* and found that a dietary level of 40% of glucose, sucrose, dextrin, and starch was well tolerated by this species. Degani and Revach²⁷) reported for tilapia *Oreochromis aureus* × *O. niloticus* a higher digestibility of carbohydrates (from wheat and corn sources) than common carp and African catfish *Clarias gariepinus*.

Acknowledgments We would like to express our sincere thanks to the Laboratory of Nippon Formula Feed MFG. Co., Ltd. which provided

the raw and extruded corn meal for this study.

References

- 1) M. Furuichi and Y. Yone: Change of blood sugar and plasma insulin levels of fishes in glucose tolerance test. *Nippon Suisan Gakkaishi*, **47**, 761–764 (1981).
- 2) M. Furuichi and Y. Yone: Effect of insulin on blood sugar levels of fishes. *Nippon Suisan Gakkaishi*, **48**, 1289–1291 (1982).
- 3) C. B. Cowey and M. J. Walton: Intermediary metabolism, in "Fish Nutrition" (ed. by J. E. Halver), 2nd ed., Academic Press, London, 1989, pp. 259–329.
- 4) S. Shimeno, H. Hosokawa, and M. Takeda: The importance of carbohydrate in the diet of a carnivorous fish, in "Proc. World. Symp. on Finfish Nutrition and Fishfeed Technology", Vol. I, Hamburg 20–23 June, 1978, Berlin, 1979, pp. 127–143.
- 5) C. Y. Cho and S. J. Slinger: Apparent digestibility measurements in feedstuffs for rainbow trout, in "Proc. World. Symp. on Finfish Nutrition and Fishfeed Technology", Vol. II, Hamburg, 20–23 June, 1978, Berlin, 1979, pp. 239–247.
- 6) F. Bergot and J. Breque: Digestibility of starch by rainbow trout. Effects of the physical state of starch and of the intake level. *Aquaculture*, **34**, 203–212 (1983).
- 7) T. Takeuchi, K.-S. Jeong, and T. Watanabe: Availability of extruded carbohydrate ingredients to rainbow trout *Oncorhynchus mykiss* and carp *Cyprinus carpio*. *Nippon Suisan Gakkaishi*, **56**, 1839–1845 (1990).
- 8) E. Pfeffer, J. Beckmann-Toussaint, B. Henrichfreise, and H. D. Jansen: Effect of extrusion on efficiency of utilization of maize starch by rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, **96**, 293–303 (1991).
- 9) K.-S. Jeong, T. Takeuchi, N. Okamoto, and T. Watanabe: The effect of dietary gelatinized ratios at different dietary energy levels on growth and characteristics of blood in rainbow trout fingerlings. *Nippon Suisan Gakkaishi*, **58**, 937–944 (1992).
- 10) S. J. Kaushik and A. Oliva Teles: Effect of digestible energy on nitrogen and energy balance in rainbow trout. *Aquaculture*, **50**, 89–101 (1985).
- 11) S. J. Kaushik, F. Medale, B. Fauconneau, and D. Blanc: Effect of digestible carbohydrates on protein/energy utilization and on glucose metabolism in rainbow trout (*Salmo gairdneri* R.). *Aquaculture*, **79**, 63–74 (1989).
- 12) B. Henrichfreise and E. Pfeffer: Wheat and wheat starch as potential sources of digestible energy for rainbow trout (*Oncorhynchus mykiss*). *J. Anim. Physiol. a. Anim. Nutr.*, **67**, 143–147 (1992).
- 13) J.-Y. Chiou and C. Ogino: Digestibility of starch in carp. *Nippon Suisan Gakkaishi*, **41**, 465–466 (1975).
- 14) M. Furuichi, G. Ito, and Y. Yone: Effect of β -starch on growth, feed efficiency, and chemical components of liver, muscle, and blood of carp and red sea bream. *Nippon Suisan Gakkaishi*, **53**, 1437–1442 (1987).
- 15) K.-S. Jeong, T. Takeuchi, N. Okamoto, and T. Watanabe: The effect of dietary gelatinized ratios at different dietary energy levels on growth and characteristics of blood in carp fingerlings. *Nippon Suisan Gakkaishi*, **58**, 945–951 (1992).
- 16) K.-S. Jeong, T. Takeuchi, and T. Watanabe: Improvement of nutritional quality of carbohydrate ingredients by extrusion process in diets of red sea bream. *Nippon Suisan Gakkaishi*, **57**, 1543–1549 (1991).
- 17) S. J. Kaushik, P. Luquet, D. Blanc, and A. Paba: Studies on the nutrition of Siberian sturgeon, *Acipenser baeri*. I. Utilization of digestible carbohydrates by sturgeon. *Aquaculture*, **76**, 97–107 (1989).
- 18) T. Takeuchi, T. Arakawa, Y. Shiina, S. Satoh, K. Imaizumi, S. Sekiya, and T. Watanabe: Effect of dietary α - and β -starch on growth of juvenile striped jack and yellowtail. *Nippon Suisan Gakkaishi*, **58**, 701–705 (1992).
- 19) L. Ding: Grass carp, *Ctenopharyngodon idella*, in "Handbook of Nutrient Requirements of Finfish" (ed. R. P. Wilson), CRC Press Inc., Boston, 1991, pp. 89–96.
- 20) P. Luquet: Tilapia, *Oreochromis* spp., in "Handbook of Nutrient Requirements of Finfish" (ed. R. P. Wilson), CRC Press Inc., Boston, 1991, pp. 169–179.
- 21) S. Satoh, C. Y. Cho, and T. Watanabe: Effect of fecal retrieval timing on digestibility of nutrients in rainbow trout diet with the Guelph and TUF feces collection systems. *Nippon Suisan Gakkaishi*, **58**, 1123–1127 (1992).
- 22) A. Furukawa and H. Tsukahara: On the acid digestion method for the determination of chromic oxide as an index substance in the study of digestibility of fish feed. *Nippon Suisan Gakkaishi*, **32**, 502–506 (1966).
- 23) K. Kainuma: Denpun no amirase shoukasei no sokuteihou, Keirin, Tokyo, 1982, pp. 641–645 (in Japanese).
- 24) B. Hopher: Nutrition of Pond Fishes, Cambridge University Press, Cambridge, 1988, p. 50.
- 25) A. T. Law: Digestibility of low-cost ingredients in pelleted feed by grass carp (*Ctenopharyngodon idella* C. et V.). *Aquaculture*, **51**, 97–103 (1986).
- 26) J. Anderson, A. J. Jackson, A. J. Matty, and B. S. Capper: Effects of dietary carbohydrate and fibre on the tilapia *Oreochromis niloticus* (Linn.). *Aquaculture*, **37**, 303–314 (1984).
- 27) G. Degani and A. Revach: Digestive capabilities of three commensal fish species: carp, *Cyprinus carpio* L., tilapia, *Oreochromis aureus* $\times$ *O. niloticus*, and African catfish, *Clarias gariepinus* (Burchell 1822). *Aquat. and Fish. Management*, **22**, 397–403 (1991).
- 28) C. Ogino, L. Takeuchi, H. Takeda, and T. Watanabe: Availability of dietary phosphorous in carp and rainbow trout. *Nippon Suisan Gakkaishi*, **45**, 1527–1532 (1979).
- 29) C. Ogino and G. Y. Yang: Requirement of rainbow trout for dietary zinc. *Nippon Suisan Gakkaishi*, **44**, 1015–1018 (1978).