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Effects of modulation dietary gelatinized cornstarch/protein ratio on growth performance, feed utilization, and body composition of tilapia *Oreochromis niloticus* fingerlings

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ABSTRACT

A 56-day feeding experiment was conducted to determine the effects of modulated dietary gelatinized maize starch with protein level on the growth and feed utilization of juvenile *Oreochromis niloticus.* Four experimental diets (G16P28, G21P26, G26P23, and G34P25) contained gelatinized cornstarch at gradual incorporation level of 30%, 40%, 50%, or 60%, as replacement for fishmeal component of the control diet (G0P35). Final body weight and specific growth rate (SGR) were highest in fish fed control diet and diet containing 16% of gelatinized cornstarch and 28% of protein (G16P28). Feed conversion ratio was significantly influenced by the different dietary treatments ($P < 0.05$), with higher values obtained in fish fed G31P21 diets. Protein gain and lipid gain increased with increasing dietary gelatinized cornstarch level in linking to decrease of nitrogenous losses and net energy retention indicating protein-sparing effect of gelatinized cornstarch in tilapia diet. The whole-body proximate composition was significantly affected by the different treatments. In view of the growth results and the economic evaluation, inclusion of gelatinized starch has substantially reduced the cost of feed and increased economic profitability.

1. INTRODUCTION

Fish is the preferred food of human nutrition because of its high content of high biological value proteins and its exceptional richness in omega-3 polyunsaturated fatty acids, vitamins, minerals, and trace elements [1].

Globally, consumption is close to 20 kg/capita/year and aquaculture with its high growth currently supplies more than half of the demand for human consumption [2]. Tilapia is among the highest fish in the world, and its production has increased sharply in recent years [3]. World aquaculture production of tilapia *Oreochromis niloticus* increased to 4 million tons in 2015 [4]. Africa represents 20% of this production largely supplied by Egypt. Sub-Saharan African countries accounted for <4% of global tilapia production [5]. Although tilapia is a native of Sub-Saharan Africa and well appreciated by the population, farming of this fish has not yet achieved sustainable economic development in these African countries.

Increasing the level of aquaculture production to meet future fish demand will largely depend on the availability of quality feed at affordable prices in the quantities required, as feed accounts for 50–80% of fish production cost [6]. Therefore, the formulation of feed that meets fish nutritional requirement is a major challenge for both commercial and farm-made feed production sectors [2]. Among feed ingredients used in the formulation of aquafeeds, fish meal remains the best source of protein. However, fish meal is still expensive and its supply contributes in part to the depletion of natural fish stocks [1]. In the next decade, the use of fishmeal in aquaculture feed will be reduced from 26% to 12% for marine fish and from 3% to 1% for tilapia followed by increased use of plant raw materials as a source of lipid and protein to replace fish oils and meal [7]. Thus, alternative protein source is explored and studied during the past decades [7]. Several plants or other invertebrate animals which contain appreciable quantity of protein with good amino acid profile have been recommended as complete or partial fish meal substitutes in fish diet [8,9]. In Fish, dietary proteins provide essential and non-essential amino acids which are the preferential nutrient used for energy production for maintenance and growth [10]. For a given raw material, it is rather the energy and nutrients they provide that are essential for fish [11]. Thus, several studies have investigated the sources of non-protein energy such as lipids and carbohydrates in fish feed.

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Carbohydrate sources such as cereals and legumes are abundant in nature and are a relatively cheaper source of energy [12]. Cereals are the most important food source in the world, both for direct human consumption, and indirectly, as inputs for animal production.

In general, the use of carbohydrate sources is more facilitated in herbivorous fish such as tilapia *O. niloticus* [13], due to their enzymatic structure which is better adapted, especially the existence of more important amylase activity [14]. Technological treatment (extrusion and gelatinization) can improve the digestibility of carbohydrates [15]. Recently, Yéo *et al.* [16] showed that a dietary cornstarch gelatinized at 70°C improves growth performance and nutrient utilization in juvenile *O. niloticus*. The aims of the present study were to investigate the effects of modulation gelatinized cornstarch/protein ratio into diet on growth performance, nutrients utilization, and body composition of fingerlings of tilapia *O. niloticus* and to determine appropriate inclusion in feed formulation for fish.

2. MATERIALS AND METHODS

2.1. Experimental Rearing Conditions

The study was conducted at the hatchery of the Center of Research for Oceanology (CRO, Abidjan, Côte d'Ivoire). 150 fingerlings of tilapia *O. niloticus* (24.81 ± 1.68 g) were obtained from the stock of fish at the experimental aquaculture station of CRO. The fish were randomly distributed in the glass tanks of hatchery with 10 fish per tank. The fish were randomly distributed in the experimental aquaria of the hatchery with 10 fish per aquaria. Fifteen aquaria of 50 L containing 45 L of water in a closed circuit were used for this experiment. The flow of water was ensured at all times by an electric motor pump allowing a flow of 1.5 L/min. The filtration was carried out by settling, and water renewal of 30% was performed daily. Water quality was monitored throughout the study with a multiparameter (BANTE 900P) for the temperature and dissolved oxygen and pH meter (WTW 330) for pH. The water temperature, pH, and dissolved oxygen were varied between 27.08–28.57°C, 6.99–7.22, and 6.15–6.94 mg/L, respectively, and were considered favorable in fish culture tanks according to the study of Boyd [17].

2.2. Experimental Diets and Methods

The raw materials such as fish meal, soybean meal, wheat bran, corn, and cassava used in this study were purchased at the local market of Abidjan. All ingredients were ground to a suitable size and mixed in a commercial mixer (KENWOOD CHEF).

Five experimental diets were prepared using a kitchen meat grinder with a 3 mm diameter (Panasonic MK-G 1800P). A control diet (G0P35) was based on fish meal and soybean meal as protein sources. The four test diets (G16P28, G21P26, G26P23, and G34P25) contained gelatinized cornstarch at gradual incorporation level of 30%, 40%, 50%, or 60%, as replacement for fishmeal component of the control diet. Gelatinized cornstarch and wheat bran were used as a source of carbohydrates, and crude fish oil was used as a lipid source. The analytical composition of feed formulations is presented in Table 1.

The different diets were tested in triplicate and fed *ad libitum* twice daily (8 am and 4 pm) for a period of the experimentation. Before starting the feeding trials, 40 fish sampled from aquaria were killed and kept in the freezer (−20°C) for body composition analysis. The same action was repeated at the end of the experiment but with all the fish from each aquarium that was previously weighed individually.

2.3. Chemical Analysis

Chemical analysis of diets and fish was determined following the standard methods [18]. Calculation of the energetic content was done using the equivalent values of proteins, lipids, and carbohydrates [19].

2.4. Zootechnical Parameters

Daily weight gain, specific growth rate (SGR), feed conversion ratio (FCR), protein efficiency ratio (PER), protein gain (PG), lipid gain (LG), nitrogen loss (NL), net energy retention (NER), and gross energy (GE) were calculated as follows:

SGR (%/d) = 100 (Ln final body weight [FBW]–Ln initial body weight [IBW])/d:

Where IBW is the IBW, FBW is the FBW, and d is the duration of the experiment (day)

FCR = Dry feed consumed (g)/wet weight (g)

PER = Wet weight gain (g)/protein consumed (g)

Protein or LG (g/kg/d) = Final carcass nutrient (protein or lipid) content–initial carcass nutrient (protein or lipid)

GE (kJ/g) = 22.2×protein content+38.9×lipid content+17.2×carbohydrate content [19]

NL (g/kg/d) = nitrogen intake (g/kg/d)–nitrogen gain (g/kg/d)

NER (%) = [(final body GE)–(initial body GE)/feed consumed GE]×100.

2.5. Economic Evaluation

The assessment of the economic cost of the diets was made on the basis of the different prices of raw materials encountered on the local market. The price of 100 g of diet and the quantity of feed required per diet to produce 100 g of weight gain was evaluated according to the following formulas:

$P_1 = \Sigma [R \times Z/1000]$

where

P_1: Price of 100 g of feed formulated by experimental diet (F CFA)

R: Price of kg of raw materials (F CFA)

Z: Quantity of each raw material in 100 g of feed formulated by experimental diet (g)

$P_2 = FCR \times P_1$

P_2: Price of the quantity of feed needed to produce 100 g of weight gain (F CFA F)

FCR: Feed conversion ratio.

2.6. Statistical Analysis

Results were analyzed with analysis of variance using Statistical Version 7.1 software package. When significant, Duncan's multiple range test was used to compare differences between means. All percentage and ratio data were arcsine transformed before analysis [20].

Table 1: Ingredients and proximate composition of the experimental diets (% dry weight).

Gelatinized cornstarch/protein ratio	Experimental diets				
	G0P35	G16P28	G21P26	G26P24	G31P21
	0/35	16/28	21/26	26/24	31/21
Ingredients (%)					
Fish meal	52	36.4	31.2	26	20.8
Soybean meal	18	18	18	18	18
Wheat bran	20	20	20	20	20
Gelatinized cornstarch	0	15.6	20.8	26.0	31.20
Cassava starch	3	3	3	3	3
Fish oil	5	5	5	5	5
Vitamin mixture[1]	1	1	1	1	1
Mineral mixture[2]	1	1	1	1	1
Proximate composition (%)					
DM	89.82	90.34	90.49	90.64	90.57
Crude protein	35.43	28.34	26.02	23.67	21.32
Crude lipid	11.1	9.65	9.28	8.83	8.37
Ash	12.83	9.59	8.59	7.53	6.48
Crude fiber	2.97	2.97	2.97	2.97	2.97
Carbohydrate	30.07	44.33	46.10	53.82	61.53
Digestible energy (kJ/g diet)	13.57	13.34	13.25	13.18	13.11
P/E (mg protein/kJ diet)	26.11	21.27	19.62	17.52	16.26

DM: Dry matter, P/E: Protein/energy ratio, [1]Per kg premix: Cobalt 20 mg, iron 17600 mg, iodine 2000 mg, copper 1600 mg, zinc 60000 mg, manganese 10000 mg, selenium 40 mg, [2]Per kg premix: Vitamin A 1 760 000 IU, Vitamin D_3 880000 IU, Vitamin E 22000 mg, Vitamin B^1 4400 mg, Vitamin B^2 5280 mg, Vitamin B^6 4400 mg, Vitamin B 1236 mg, Vitamin C 151000 mg, Vitamin K 4400 mg, Vitamin *P* 35200 mg, folic acid 880 mg, choline chloride 220000 mg, pantothenic acid D 14080 mg.

3. RESULTS AND DISCUSSION

3.1. Growth Performance

During the experiment, the recorded physicochemical parameters of water were in conformity with the recommended conditions for tilapia farming [21,22]. Data of fish growth are reported in Table 2. Survival rates ranged from 76.67 ± 5.77 to 86.67 ± 15.28% and were not significantly different between treatments ($P > 0.05$). FBW ranged from 44.75 ± 4.65 to 59.92 ± 3.59 g and SGR from 1.63 ± 0.13 to 1.06 ± 0.13% d^{-1}, with the highest values obtained in fish fed with diets G16P28 and G0P31. The difference between these two treatments for growth parameters was not significant. Several studies have shown that the digestibility of carbohydrate sources in fish can be affected by different nutritional and environmental factors [23-26]. In specific levels, dietary carbohydrates constituted an alternative source of energy for fish growth. This experiment yielded quite acceptable growth results when comparing the experimental diet G16P28 (containing 16% of gelatinized cornstarch and 28% of protein) to the control diet G0P35 (35% of protein without gelatinized cornstarch). These results are in agreement with those of Wang *et al.* [27] who reported better growth in hybrid tilapia *O. niloticus* x *Orecohromis aureus* fed with diet containing 22% dietary starch. In *O. niloticus* also, Wang *et al.* [28] found an improvement in growth when fed a supplemented diet with 20% of starch. In other fish species, the same growth pattern related to the use of starch sources has been observed. In juvenile cobia, *Rachycentron canadum*, an improvement of growth performance was observed with 21.1% of dietary starch [29]. Similar effects were observed in gibel carp Carassius auratus gibelio and grass carp *Ctenopharyngodon idellus* fed with 30% [30]. The juvenile yellowfin seabream *Sparus latus* Houttuyn also had better growth performance when fed with 20% inclusion level of raw cornstarch in the diet.

3.2. Feed an Nutrient Utilization

FCR was significantly different between treatments ($P < 0.05$) and the highest value was obtained in fish fed the G31P21 diet. Fish fed with control diet (G0P35) and diet G16P28 showed similar PER that ws significantly higher than those determined in fish from other treatments ($P < 0.05$). Better FCR and PER were observed in fish fed with diet G16P28 unlike other experimental diets that showed a decrease in PER. These results showed that diet G16P28 was the appropriate diet for better growth of fish. In this diet, the fishmeal in the control diet was substituted for 30% by gelatinized cornstarch, indicating that modulation of the dietary ratio with 16% of gelatinized cornstarch and 28% of protein allowed fish to better utilize the energy provided by gelatinized cornstarch for their growth. This assertion was in agreement with those of Oliva-Teles [31] which showed that energy and starch digestibility are improved with the use of dietary gelatinized starch.

PG increased with increasing gelatinized cornstarch level in diet, with the highest value recorded in fish fed with diet G31P21, containing 31% gelatinized cornstarch. Similar trend was found for LG responses. NLs were greater (10.98 ± 1.37 g/kg/d) in fish fed with control diet (G0P35) and the lowest value was 6.84 ± 0.54 g/kg/d in fish fed with G31P21 diet. NER ranged from 20.29 ± 3.06 to 35.04 ± 7.41%, with the highest values observed in fish received the control diet (G0P35), but this value was not statically different from those recorded with diets G16P28 and G21P26.

The inclusion of gelatinized cornstarch in diets seems to influence the nutrient utilization. PG and LG increased with increasing dietary gelatinized cornstarch level, and this was followed by a decrease in NER and NL. These observations were in agreement with some others studies [28,31]. Whoever contrary in this study, Oliva-Teles [31] reported a decrease in energy retention with the increase of dietary gelatinized cornstarch. The fact that PG increased with increasing dietary gelatinized cornstarch in linking to decrease of NL and NER would indicate protein-sparing effect of gelatinized cornstarch in tilapia diet as reported in previous studies [27,28].

3.3. Whole-body Proximate Composition

Fish whole-body protein and lipid content was significantly influenced by the different treatments [Table 3]. The maximum whole-body protein (15.79 ± 0.31 %) was observed in fish fed with diet G21P26. The highest body lipid content (6.16 ± 0.49%) was obtained from fish fed with diet G31P21, containing the highest gelatinized cornstarch level (31%), and the lowest body lipid value was recorded in fish fed with control diet (without gelatinized cornstarch). The whole-body moisture contents were inversely correlate to lipid content. Fish whole-body energy and ash level were not statically different between treatments ($P < 0.05$) [Table 3].

Whole-body protein and lipid were increased with increasing dietary gelatinized cornstarch. The increase in body lipid content related to the gelatinized cornstarch level in the diet was followed by a decrease in body moisture content. Similar results were shown with juvenile *O. niloticus* x *O. aureus* [27] and *O. niloticus* [28]. These results could be explained by the metabolic processes of the use of starch-rich diets in tilapia [28]. The authors were found an increasing whole-body protein and lipid content correlated with an increase in plasma triglyceride concentrations, total glucose cholesterol, hepatic glycogen levels, and the activities of hepatic enzymes such as glucokinase, pyruvate kinase, and lipoprotein lipase, when the fish was fed with feed containing gradual levels of cornstarch.

Body ash content was negatively related to gelatinized cornstarch level. In contrast to lipids, the body ash content was negatively correlated with the dietary gelatinized starch level. Similar results have also been reported in juvenile tilapia *O. niloticus* x *O. aureus* [27].

3.4. Economic Evaluation

Economic evaluation of the experimental diets is shown in Table 4. Compared to the control diet (G0P31), diets containing gelatinized cornstarch had the lowest costs. The lowest cost was obtained with diet G31P21 (containing 31% gelatinized cornstarch and 21% of protein). In terms of economic performance, fish produced with experimental feeds are more profitable.

Table 2: Growth performance and nutrient utilization of *O. niloticus* fingerlings after 56 days of feeding experimental diets.

Gelatinized cornstarch/protein ratio	Experimental diets				
	G0P35	**G16P28**	**G21P26**	**G26P24**	**G31P21**
	0/35	**16/28**	**21/26**	**26/24**	**31/21**
Parameters					
IBW (g)	24.07±1.4	24.09±1.83	24.63±1.16	24.81±1.69	24.59±1.23
FBW (g)	59.92±3.59^{b}	60.29±4.51^{b}	50.09±2.89^{a}	47.02±4.37^{a}	44.75±4.65^{a}
Survival (%)	82±10.00^{a}	80.33±5.77^{a}	76.67±5.77^{a}	86.67±15.28^{a}	80.00±10^{a}
GWG (g/d)	0.64±0.06^{c}	0.66±0.05^{c}	0.45±0.07^{ab}	0.4±0.08^{ab}	0.36±0.07^{a}
SGR (%/d)	1.63±0.13^{c}	1.60±0.06^{c}	1.27±0.17^{ab}	1.14±0.2^{ab}	1.06±0.13^{a}
FCR	1.30±0.20^{a}	1.25±0.06^{ab}	1.39±0.22^{abc}	1.59±0.33^{bc}	1.73±0.3^{c}
PER	3.55±0.73^{b}	3.25±0.21^{b}	2.18±0.36^{a}	2.08±0.48^{a}	2.41±0.39^{a}
PG (g/kg/d)	2.57±0.76^{a}	2.76±0.66^{a}	3.54±0.91^{ab}	3.51±0.55^{ab}	4.77±1.24^{b}
LG (g.kg/d)	1.06±0.24^{ab}	1.1±0.2^{abc}	1.39±0.32^{bc}	1.65±0.25^{cd}	2.04±0.49^{d}
NL (g/kg/d)	10.98±1.37^{c}	9.02±0.52^{b}	8.37±0.54^{ab}	7.33±1.38^{ab}	6.84±0.54^{a}
NER (%)	35.04±7.41^{b}	27.69±2.38^{ab}	27.05±5.84^{ab}	24.90±4.91^{a}	20.29±3.06^{a}

Means in a row with different superscripts significantly (P<0.05). IBW: Initial body weight, FBW: Final body weight, DWG: Daily weight gain, SGR: Specific growth rate, FCR: Feed conversion ratio, PER: Protein efficiency ratio, PG: Protein gain, LG: Lipid gain, NL: Nitrogen loss, NER: Net energy retention. GWG: Gestational weight gains, *O. niloticus: Oreochromis niloticus*.

Table 3: Whole-body composition (% wet weight basis) of *O. niloticus* fingerlings after 56 days of feeding experimental diets.

Gelatinized cornstarch/protein ratio	Experimental diets					
	Initial	**G0P35**	**G16P28**	**G21P26**	**G26P24**	**G31P21**
		0/35	**16/28**	**21/26**	**26/24**	**31/21**
Parameters						
Moisture (%)	75.1	74.37±0.32^{a}	73.63±0.33^{ab}	72.42±1.48^{bc}	71.98±1.44^{c}	69.8±0.14^{d}
Crude protein (%)	13.78	14.25±0.28^{a}	15.63±0.17^{bc}	15.79±0.31^{c}	15.67±0.46^{bc}	14.31±0.01^{ab}
Crude lipid (%)	4.00	5.33±0.38^{a}	5.52±0.25^{ab}	5.62±0.02^{ab}	5.88±0.01^{ab}	6.16±0.49^{b}
Ash (%)	3.94	5.08±0.25^{c}	4.29±0.52^{b}	3.96±0.93^{a}	3.84±0.3^{a}	3.61±0.86^{a}
GE (kJ/g)	5.16	5.52±0.11^{a}	5.8±0.16^{a}	5.88±0.48^{a}	5.94±0.43^{a}	5.59±0.21^{a}

Means in a row with different superscripts significantly (P<0.05). *O. niloticus: Oreochromis niloticus*, GE: Gross energy.

Table 4: Economic evaluation of experimental diets.

Ingredients	Cost (F CFA[1]/kg)	Experimental diets				
		G0P35	G16P28	G21P26	G26P23	G31P21
Fish meal	600	31.8	22.26	19.08	15.9	11.13
Soybean meal	340	11.56	11.56	11.56	11.56	11.56
Wheat bran	120	0.6	0.6	0.6	0.6	0.6
Gelatinized starch	350	0	5.57	7.42	9.28	12.06
Cassava starch	300	0.6	0.6	0.6	0.6	0.6
Fish oil	700	2.8	2.8	2.8	2.8	2.8
Vitamin mixture	1000	1	1	1	1	1
Mineral mixture	1000	1	1	1	1	1
Cost of feed (CFA/100 g)		49.39	45.39	44.06	42,74	40.75
Price of fish (F CFA/100 g weight gain)		49.39	56.74	61.24	67.95	70.5

[1]FCFA (Franc CFA): 1 US dollar (USD) amounts to 531.17 FCFA West Africa (XOF), during the purchase of ingredients on the local market during the period of study (January-February 2016).

In view of the growth results and the economic evaluation of the experimental diets, it appeared that the diet formulated with 16% of gelatinized cornstarch and 28% of protein (G16P28) could be recommended in the practical diets for tilapia. This diet indeed allowed to obtain growth performance similar to control diet. In terms of ingredient costs, fish meal was twice more expensive than gelatinized cornstarch. Inclusion of gelatinized starch has substantially reduced the cost of feed and increased economic profitability. Similar results were obtained with the inclusion of starch in the diet of larvae of *Atractosteus tropicus* [32].

4. CONCLUSION

In this study, gelatinized cornstarch was gradually incorporated in diet of tilapia *O. niloticus* fingerlings, by modulation with protein levels. The results showed that diet formulated with 16% of gelatinized cornstarch and 28% of protein improved fish growth and nutrient utilization. The use of gelatinized starch could be recommended in practical diet of tilapias, thereby reducing the cost of diets.

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