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Potential use of corn co-products for fishmeal-free diets for juvenile Nile tilapia *Oreochromis niloticus*

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ティラピア *Oreochromis niloticus* 稚魚用無魚粉飼料におけるトウモロコシ副産物の有効性

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ティラピア *Oreochromis niloticus* 稚魚用無魚粉飼料におけるトウモロコシ副産物の有効性を評価した。すなわち、魚粉または濃縮トウモロコシタンパク、コーングルテンミール、高タンパクトウモロコシ蒸留粕（HPDDG）、可溶性物含有トウモロコシ蒸留粕(DDGS)を含む飼料を作製し、4.5 g の魚に 12 週間給餌した。対照区および DDGS 飼料を給餌区で有意に高い飼育成績が得られ、次いで HPDDG 区で優れた成績が得られた。また、全魚体と筋肉中タンパク質含量も HPDDG 区で最も高く、脂質含量は DDGS 区で高かった。DDGS はティラピア用飼料の魚粉を完全に代替するのに有効であると示唆された。

Abstract

We conducted a 12-week feeding trial to evaluate the effects of total fishmeal replacement with different corn co-products on growth performance, feed utilization efficiency and body composition in juvenile Nile tilapia *Oreochromis niloticus*. Five isonitrogenous diets were prepared. Fifty per cent of the dietary protein was obtained from fishmeal (control diet) or from one of four corn co-products, namely corn protein concentrate, corn gluten meal, high-protein distillers' dried grains (HPDDG) or distillers' dried grains with solubles (DDGS) (experimental diets). Fish with an initial mean weight of 4.5 g were fed one of the five diets twice a day to near satiety. Significantly higher ($P< 0.05$) specific growth rates and survival occurred in fish fed the control diet or DDGS, followed by HPDDG; mean feed intakes by fish in these three groups were significantly greater than those in the others. Food conversion ratio, protein efficiency ratio, and total amino acid content of whole body were not affected by changes in dietary ingredients. Whole body and fillet protein content was highest in the HPDDG group, and lipid content was highest in those fed DDGS. DDGS can be used to fully replace the fishmeal component of Nile tilapia diets.

Key words: amino acids, DDGS, feed utilization, fillet quality, growth performance, HPDDG

1. Introduction

The search for alternatives to replace the fishmeal component of aqua-feed has received a good deal of attention, resulting in considerable research progress, over the last two decades. A vast array of proteins from both plant and animal sources has been evaluated widely for their suitability for partial or total replacement of fishmeal in aqua-feeds [1-7]. Among the tested ingredients, industrial by-products or co-products that are considered unsuitable for direct human consumption have received much interest [8]. In this context, protein-rich co-products of the corn-milling industry play an important role as protein sources for the manufacturing of animal feeds, including aqua-feeds.

Corn gluten meal (CGM) and corn protein concentrate (CPC) are co-products of the corn wet-milling industry, and CGM has been used widely in aqua-feeds[9]. Distillers' dried grains with solubles (DDGS) and high-protein distillers' dried grains (HPDDG) are co-products of corn dry-milling industries for fuel ethanol production. HPDDG is a relatively new product of the corn ethanol industry, and its nutritional value is much more consistent than that of DDGS [10] . Unlike other, conventional, plant protein sources such as soybean meal and cotton seed meal, corn co-products are free from anti-nutritional factors [11, 12]and few amino acids deficiencies were reported [13]. However, differences among variety of corn co-products, such as percentage protein can be identified due to the differences in the wet-milling and dry-milling processes.

Aquaculture of tilapia, a group of fish with herbivorous or omnivorous feeding habits is the most widespread in the world. Dietary substitution of fishmeal with an alternative protein source in herbivorous or omnivorous species is considerably easier than in carnivorous species, which are nutritionally more demanding[14].

Because tilapia can utilize a high percentage of dietary plant ingredients [15], co-products of the corn-milling industry such as CGM and DDGS have been tested in their diets, with varying degree of success [1-3, 5, 16, 17]. However, total fishmeal replacement with a single corn co-product has not yet been evaluated in this fish, and to our knowledge no attempt has been made to compare multiple corn co-products

as fishmeal alternatives in a single growth trial. Our objectives here were to 1) compare the effects of total fishmeal replacement with various single corn co-products in the diet of Nile tilapia *Oreochromis niloticus*, juveniles, on growth performance, feed utilization efficiency, and body composition; and 2) determine the most suitable corn co-product for use in a zero-fishmeal diet for these fish.

2. Materials and Methods

2.1 Experimental diets

Five isonitrogenous (32% protein) experimental diets (fishmeal-based control diet and four corn co-product-based diets) were formulated to fulfil the known nutritional requirements of juvenile Nile tilapia [18]. Proximate composition of main protein sources and ingredient composition of diets are given in Table 1 and 2 respectively. In the control diet, 50% of the protein was supplied by fishmeal. In the other four diets, the fishmeal component of the control diet was fully replaced with one of four corn co-products, namely CPC, CGM, HPDDG or DDGS. Crystalline amino acids (DL- methionine & L-lysine) were used to compensate the amino acid deficiencies in corn based diets.

< **Table 1-2** >

The proximate composition and total amino acid composition of the experimental diets is presented in Table 3. Before feed preparation, the ingredients were ground to pass through a mesh (0.5 µm) screen and then mixed by using a horizontal mixer. The mixture was then moistened by adding distilled water (~20%), pelleted and freeze-dried. Diets were stored at 5 ˚C until use. The names of the five diets were designated according to the main protein ingredient, namely control (FM), CPC, CGM, HPDDG and DDGS.

<**Table 3** >

2.2 Experimental fish and rearing condition

Nile tilapia fingerlings were obtained from the Laboratory of Fish Culture, Tokyo University of Marine Science and Technology, Tokyo, Japan. Before the start of the experiment, the fish were acclimated to the experimental conditions for two weeks. During this acclimation period, fish were hand fed to near satiety twice a day by using the control diet. After the acclimatization period food was withheld for 24 h, after which 200 fish with similar initial body weights (4.0 to 4.5 g) were selected for potential use in the experiment. Groups of 18 fish were bulk weighed and stocked into each glass tank (60 L). Five treatments, one for each diet (control, CPC, CGM, HPDDG and DDGS), in duplicate were randomly allocated to ten (2 × 5) glass tanks. Each tank was connected to a freshwater re-circulating system in which the water temperature was maintained at 28 ± 1 ˚C by using electrical heaters (immersion heaters). The water flow rate was maintained at 0.5 L min $^{-1}$, and aeration was provided continuously to each tank via submerged air stones. Approximately 50% of the water in the re-circulating system was replaced with de-chlorinated tap water once every two weeks. Fish were hand fed to near satiety twice a day, 6 days a week for 12 weeks, and daily feed intakes were recorded.

2.3 Data collection and sampling

The 20 fish remaining in the initial stock of 200 were sacrificed by using an overdose of 2-phenoxyethanol and kept at –30 ˚C for initial carcass analysis. During the 12-week experiment, the fish in each tank were bulk weighed at 3-week intervals. At the end of the experiment, fish were starved for 24 h and anaesthetized with 0.2% 2-phenoxyethanol before being handled. The weight and length of the fish in each tank were individually measured with an electrical balance and a measuring board, respectively, to the nearest first decimal point.

Five average-size fish from each tank were euthanized using overdose of 2-phenoxyethanol and used to calculate the hepatosomatic index (HSI), viscerosomatic index (VSI) and fillet yield (FY). Four fish from each treatment and the fillet samples used for fillet yield determination were immediately frozen at –30 ˚C for final chemical analysis. Frozen samples were minced, freeze-dried and kept at –30 ˚C until analysis.

Percentage specific growth rate (SGR, %), thermal growth coefficient (TGC), food conversion ratio (FCR), protein efficiency ratio (PER), Protein retention (%),survival rate (SR, %), HSI, VSI, fillet yield and the coefficient of condition (K) were calculated by using the following equations to compare fish growth, nutrient utilization efficiency, and body indices among treatments.

SGR = (ln FW – ln IW) / no. of days × 100

TGC = [(FW 1/3 – IW 1/3) / (water temperature ˚C) × no. of days)] × 1000

FCR = feed intake (dry basis) / wet weight gain

PER = body weight gain (g)/ protein intake (g)

Protein retention (%) = (final body protein – initial body protein) / protein intake × 100

SR = number of fish at harvest / number of fish stocked × 100

HSI = liver weight / body weight× 100

VSI = visceral weight / body weight× 100

Fillet yield = fillet weight/ body weight× 100

$K = 100 \times \text{mean weight (g)} / (\text{total length (cm)})^3$

FW, final mean weight of fish; IW, initial mean weight of fish

2.4 Chemical analysis

Feed ingredients, diets, whole body and muscle samples of fish were analysed in accordance with standard procedures for chemical analysis [19]. All the samples were finely ground and analysed in triplicate. Dry matter content was calculated from the weight loss after drying of the sample at 105 ˚C until it reached a

constant weight. Ash content was determined after the incineration of samples in a muffle furnace at 550 ˚C for 16 h. The Kjeldhal method was used for crude protein analysis. Crude lipid content was determined by the gravimetric method after extraction of the lipids into a mixture of chloroform and methanol (2:1 v/v).

Amino acid content was analysed by using an automatic amino acid analyser (JLC-500/v; JEOL, Tokyo, Japan)[20]. For total amino acids, samples were digested at 110 ˚C for 22 h with 4 M methanosulphonic acid (Sigma-Aldrich, St. Louis, MO, USA); the digested solution was then passed through a 0.45-µm membrane filter and injected into the analyser.

2.5 Statistical analysis

Data were initially checked for normality and equal variance by using Levene's test for equality of variances. The effects of different corn co-products on Nile tilapia growth performance, feed utilization efficiency, body indices and whole body and fillet proximate composition were compared in a one-way analysis of variance (ANOVA) at the 5% significance level ($P< 0.05$). When ANOVA was found to be significant, Tukey's multiple range tests was used to detect differences among treatments. All statistical analyses were performed with SPSS version 16.0.

3. Results

3.1 Growth performances and feed utilization efficiencies

The initial weights of fish assigned to the different treatments (4.0 to 4.5 g) did not differ significantly ($P> 0.05$). However, final weight was significantly affected by the treatments (Fig. 1).

<Fig. 1>

Differences in the growth rates of fish fed various diets were first observed after 6 weeks. The final mean weights of fish in the five treatment groups differed significantly from each other ($P< 0.05$). The

greatest final weight was observed in the control, followed by DDGS. The lowest weight was observed in the CPC treatment. Among the corn-based test diets, DDGS gave a significantly greater final mean weight, followed by HPDDG. Final mean weight of DDGS was almost double than that of CPC. The weights of fish in the CPC and CGM groups almost overlapped until week 9, but by the end of the experiment CGM had resulted in a significantly greater weight than did CPC.Growth performance and feed utilization efficiencies of the fish are given in Table 4.

<**Table 4**>

The % SGRs of the control and DDGS groups were significantly higher than those of the others. The lowest SGR was observed in the CPC group, followed by the CGM group. TGC differed significantly among treatments and it was highest in the control. Mean feed intake was significantly higher in the control, DDGS and HPDDG groups than in the others. Feed utilization efficiency in terms of FCR and protein efficiency ratio (PER) was independent of the type of dietary treatment. However, protein retention was significantly affected by the treatment. Protein retention in control was significantly higher than that of CPC and CGM while HPDDG and DDGS differ only from CPC. Survival rate was significantly affected by the treatment. The CPC, CGM and HPDDG groups had similar survival rates; they were significantly lower than that of the control. However, the survival rate of the DDGS group did not differ from those of the control or HPDDG group.

3.2 Whole body and fillet proximate composition

We examined the proximate compositions of the whole body and fillet (Table 5). The dry matter content of the whole body was not influenced by diet. Crude protein content of fish whole body was significantly higher in HPDDG than in the other groups, with the next-highest contents in the control and DDGS groups; these three groups had significantly higher feed intakes than the other treatment groups (see Table 4), and the control and DDGS groups had significantly higher growth rates than the others. Whole body lipid content in all the corn-based treatments was significantly higher than that of the control. Ash

content was also greatly affected by dietary treatment; it was significantly higher in the control than in the other groups; the next-highest value was in the DDGS group.

<**Table 5**>

Our data on the proximate analysis of fillet samples revealed no treatment effects on dry matter and ash. In the case of both whole body and fillet, the crude protein content was significantly higher in the HPDDG group than in the others, whereas the fillet crude lipid content was highest in DDGS. However, in the whole body or fillet the amount of protein in the control did not differ from that in DDGS; these two groups also had similar growth performances. Similar to the case in the whole body, the lowest crude lipid content in the fillet was observed in the fishmeal-based control.

We examined the total amino acid compositions of whole body at the end of the 12-week period (Table 6); these compositions were independent of treatment type.

<**Table 6**>

We also examined the morphometric indices of different treatments (Table 7). There were no significant between-group differences in any of the indices evaluated, i.e. VSI, HSI, FY, or K value.

<**Table 7**>

4. Discussion

Growth in terms of the weight of juvenile fish usually follows a sigmoid curve, as we observed here in Nile tilapia. Although fish in all treatments had similar growth patterns, growth rates differed among all treatments. Growth of fish is a function of feed intake and capacity of fish to utilize ingested food [21]. Since the feed intake in this study showed significant differences among treatments, the observed variations in growth rate were likely explained by the factors affected on feed intake.

Dietary availability of essential nutrients such as amino acids is a factor which determine the feed intake of fish[22].Therefore differences in feed intake in this study can be explained by the dietary essential amino acid composition. Even if diets were formulated to fulfil the essential amino acid requirement of Nile tilapia [23] (estimated using values in [24]), analytical data showed that some amino acids such as arginine, histidine and valine are deficient in CPC and CGM diets. Essential amino acid composition of control, HPDDG and DDGS was almost similar except histidine and those were the treatment group which showed higher growth performances and feed intakes compared to CPC and CGM. Feed intake of fish is known to reduce when dietary essential nutrients are deficient[22, 25]. Therefore differences in amino acid compositions in diets are the most plausible responsible factor for observed variation in feed intakes and thereby for differences in growth rate of fish as previously observed for Nile tilapia [26].

In addition, DDGS and HPDDG, which showed similar feed intake to the fishmeal-based control, are co-products of a corn dry-milling process, whereas CPC and CGM are co-products of corn wet-milling process. Because all four corn co-products were made from the same ingredient, the observed differences in feed intake and growth are likely attributable to difference in the corn processing method. Unlike wet-milling, dry-milling processes the whole corn kernel, which is subjected to subsequent saccharification and fermentation before the co-products are processed [26-28]. Therefore, dry-milling co-products such as DDGS and HPDDG usually contain fermentation residues, including yeast cells (*Saccharomyces cerevisiae*) [28-30] and other unidentified nutrients formed during the fermentation–distillation process [28]. Corn wet-milling uses steeping and fractionation technology to separate the corn kernel into protein, starch, oil, and fiber components, and the protein portion is not subjected to fermentation [26, 28]. Therefore, the greater feed intake and growth performance observed in the DDGS and HPDDG groups than in the CPC and CGM groups could be associated with the availability of yeast and other unidentified fermentation residues remaining in the dry-milled co-products. This hypothesis is supported by the work of [31] who reported improved growth performance of Nile tilapia juveniles fed diets supplemented with commercial live yeast (*S. cerevisiae*); they noted that the yeast enhanced appetite and consequently improved feed intake. Improved

feed consumption and growth associated with diets containing DDGS has previously been reported for the same species [32].

The % SGRs of fish in the control, DDGS and HPDDG groups were similar to those reported for Nile tilapia of similar size by [32, 33] but slightly higher than those observed by [34]. Even though the % SGRs were lower in the CPC and CGM treatments than in the other treatments, our values were consistent with the reported values in the literature for Nile tilapia of similar size reared at 28 °C in fresh water[34, 35].

Our feed utilization efficiencies in terms of FCR and PER were independent of the treatment type despite the large differences in growth parameters. These findings agreed with those of a previous study[26, 33].However, dietary ingredients seemed to affect on protein retention of this study and values are almost similar to what was reported in literature [36]. Fish can utilize organic macronutrients such as protein, lipid and carbohydrate as a direct metabolic fuel or store for utilization in later date or deposit in the structural materials which represent as growth [37].Protein retention in this study showed close relationship with weight gain of fish and indicated the differences in nutrient retention are partly responsible for differences of growth. Although it was difficult to distinguish statistical differences of protein retention among corn based treatments, fishmeal based control which had highest final body weight showed the higher protein retention compared to that of CPC and CGM which had lower final weight. Dietary amino acid deficiency was also observed in these two treatments and therefore, it is obvious that, protein retention was affected by the dietary amino acid composition. However difficulties in finding differences in feed utilization parameters among corn based treatment groups which were significant for growth parameters may be due to low statistical power in this study which arises with limited number of replicates used.

The whole body and fillet proximate compositions of our experimental fish were affected by the dietary ingredients. However, whole body and fillet protein content of DDGS and HPDDG was equal to or higher than that in the control. This result suggests that complete replacement of fishmeal in the tilapia diet with corn dry milling co-products does not negatively affect the final nutritional quality of fish products in terms of body protein. Because the total amino acid content of the whole body did not differ significantly among treatments, complete replacement of fishmeal with corn co-products had no negative impact even

from the perspective of essential amino acids. Whole body protein of CPC and CGM is lower than that of control, DDGS and HPDDG and these statistical differences were not exist in the fillet protein content. Therefore, lower percentage of whole body protein observed in CPC and CGM was not due to the differences in converting feed protein into fish muscle protein. Since whole body protein is the average of all structural protein and muscle protein, observed variation in whole body protein among treatments should be due to the treatment effects on structural proteins. This should be partly associated with the amino acid deficiency of CPC and CGM diets. Our fillet yield varied in a narrow range (28% to 32%) and was not affected by treatment. This indicates that Nile tilapia are capable of converting corn co-products and other ingredients into edible muscle mass at rates similar to those on a fishmeal-based diet.

In conclusion, total fishmeal replacement with different corn co-products had different effects on the growth performance and proximate composition of the fish's whole body and fillets. Among the corn co-products tested, DDGS was the best choice for a zero fishmeal diet for Nile tilapia juveniles. Because we focused here only on the juvenile stage of Nile tilapia with duplicate, a long-term growth trial with more replicates and balanced amino acid profiles in diets should be done to confirm the effects of corn co-products on the growth performance and fillet quality of marketable-size fish.

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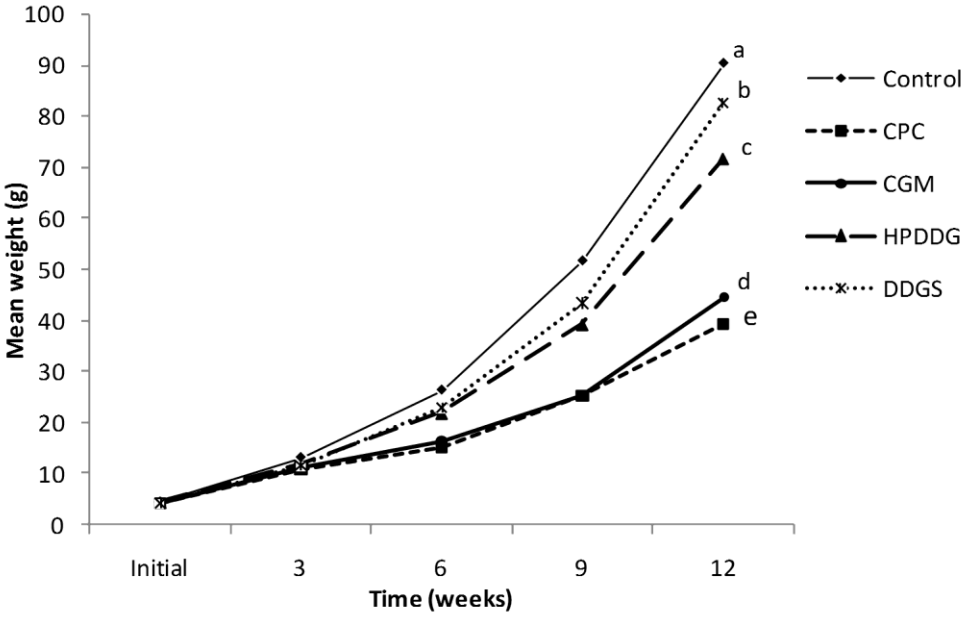
Figure captions

Fig. 1 Mean weight of fish over experimental period (n=2, different letters indicate significant differences, $p < 0.05$)

Figure


100
90
80
70
60
50
40
30
20
10
0
Mean weight (g)
Initial
3
6
9
12
Time (weeks)
a
b
c
d
e
Control
CPC
CGM
HPDDG
DDGS

Revised table

Table 1 Proximate composition (g kg^{-1}) of protein sources used in experimental diets fed Nile tilapia *Oreochromis niloticus* (n=3)

Ingredient	Dry matter	Protein	Lipid	Ash
FM	918	682	100	113
CPC	901	798	95.8	16
CGM	933	658	130	18
HPDDG	904	461	37.7	38
DDGS	896	314	77.1	66
SBM	934	458	21	63
PBM	877	690	106	101

FM, fish meal (anchovy); CPC, corn protein concentrate, Empyreal 75®, Cargill Corn Milling; CGM, corn gluten meal; HPDDG, high protein distillers dried grains, Dakota Gold ® BFRAC™, SBM, soybean meal; PBM, poultry by product meal

Table 2 Ingredient composition (g kg^{-1}) of experimental diets fed Nile tilapia *Oreochromis niloticus*

Ingredient	Control	CPC	CGM	HPDDG	DDGS
Fish meal	218	0	0	0	0
Corn co-product	0	194	235	332	524
Soybean meal	162	166	168	188	211
Poultry by product meal	51	53	52	52	71
Wheat flour	312	329	302	225	56
Alpha starch	190	176	163	121	86
Vitamin mix	10	10	10	10	10
Mineral mix	16	16	16	16	16
Soy oil	41	44	44	46	18
L-lysine	0	8	7	6	4
DL-methionine	0	4	3	4	4
Crystalline amino acids	0	12	10	10	8

CPC; corn protein concentrate based diet, CGM; corn gluten meal based diet, HPDDG; high protein distillers dried grain based diet, DDGS; distillers dried grains with soluble based diet

Vitamin mixture composition (unit kg^{-1}premix): Vitamin A, 420 000 IU; Vitamin D3, 2 420 000 IU; Vitamin K3, 6050mg; Vitamin E 1000mg; thiamine, 3025 mg; riboflavin, 3630 mg; pyridoxine, 2420 mg; cyanocobalamine, 6 mg; L-ascorbic acid, 368 900mg; nicotinic acid, 24 200mg; D-pantothenic acid, 6050mg; inositol, 121 000mg; d-biotin, 363 mg; folic acid, 908 mg; para-aminobenzoic acid 3025 mg.

Mineral mixture composition (g/kg^{-1} premix) : Sodium chloride 50; magnesium sulphate 745; iron(lll) citrate n-hydrate 125; trace element mix 50; cellulose 30 [the trace element mixture contains(g/kg^{-1}) Zinc sulphateheptahydrate 353; manganese sulphate 162; copper (ll) sulphate pentahydrate 31; aluminium chloride hexahydrate 10; cobalt chloride 3; potassium iodate 1; cellulose 440].

Table 3 Proximate and amino acid composition of experimental diets (g kg^{-1}) fed Nile tilapia *Oreochromis niloticus* (n=3)

Components	Control	CPC	CGM	HPDDG	DDGS
Dry matter	968	963	964	961	961
Protein	319	323	321	321	315
Lipid	88.7	97.2	97.4	88.9	98.4
Ash	76	38.7	34.4	45.2	56.5
EAA					
Arginine	14.8	9.1	10.5	14.1	13.9
Histidine	7.5	3.9	4.4	6.0	5.7
Isoleucine	6.8	5.6	6.5	8.5	7.7
Leucine	17.7	19.8	23.2	23.6	22.8
Lysine	15.0	11.8	12.5	16.6	14.6
Methionine	5.3	5.9	6.1	7.7	8.1
Phenylalanine	11.0	9.9	11.7	12.5	11.6
Threonine	10.3	6.8	8.0	11.0	9.9
Tryptopan	1.0	0.7	0.8	1.0	0.6
Valine	8.4	5.7	7.5	10.4	9.5
NEAA					
Alanine	15.4	12.5	14.9	16.1	15.6
Aspartic acid	25.5	15.4	18.3	24	21.9
Cysteine	2.2	2.0	2.2	3.3	3.1
Glutamic acid	45.6	40.6	47	48.5	45
Glycine	16.3	8.4	10.1	12.8	12.6
Serine	13.0	10.4	12.2	14.4	13.2
Tyrosine	8.1	7.6	9.3	10.1	9.5

CPC; corn protein concentrate based diet, CGM; corn gluten meal based diet, HPDDG; high protein distillers dried grain based diet, DDGS; distillers dried grains with soluble based diet; EAA, essential amino acid; NEAA, non essential amino acid

Table 4 Growth performances and feed utilization efficiencies of Nile tilapia fed diets containing corn co-products over 12 weeks (mean ± SD, n=2)

	Control	CPC	CGM	HPDDG	DDGS	p
% SGR	3.56 ± 0.01[a]	2.63± 0.01[d]	2.75± 0.20 [c]	3.30± 0.03[b]	3.53± 0.06[a]	*
TGC	1.21 ± 0.01 [a]	0.76 ± 0.01 [e]	0.81 ± 0.01 [d]	1.06 ± 0.01 [c]	1.16 ± 0.00 [b]	*
Feed intake (g dry weight)	84.05± 0.78[a]	38.80± 0.28[b]	40.2± 0.14[b]	71.05± 9.85[a]	81.20± 1.20[a]	*
FCR	1.00 ±0.00	1.10 ±0.00	1.00 ±0.00	1.05 ±0.15	1.05 ±0.07	ns
PER	3.20 ± 0.01	2.84± 0.11	3.10± 0.08	2.99± 0.50	3.06± 0.06	ns
Protein retention (%)	49.62 ± 0.13[a]	38.42 ± 0.78 [c]	42.02±1.63[bc]	46.17±2.91[ab]	46.70±0.81[ab]	*
% Survival	100.0± 0.0[a]	75.0± 4.0[c]	66.6± 7.8[c]	80.6± 3. 9[bc]	97.2± 3.9[ab]	*

Mean values in same row with different superscripts are statistically different ($p < 0.05$)

% SGR: percentage specific growth rate; TGC : thermal growth coefficient FCR: food conversion ratio; PER: protein efficiency ratio

ns : not significant, *: $p < 0.05$)

Table 5 Proximate composition of whole body and fillet (% wet basis) of Nile tilapia fed experimental diets over 12 weeks (Mean ± SD, n=3)

Treatment	Moisture	Protein	Lipid	Ash
Whole body				
Control	69.4 ± 1.6	15.5 ± 1.1^{b}	8.5 ± 0. 6^{b}	6.9 ± 0. 5^{a}
CPC	71.6 ± 0.8	13.9 ± 0.3^{d}	9.6 ± 1.3^{a}	5.0 ± 0. 1^{d}
CGM	70.9 ± 1.0	14. 6 ± 1.0^{c}	9.8 ± 2.9^{a}	4.0 ± 0. 4^{e}
HPDDG	68.9 ± 0.7	16. 7 ± 1.9^{a}	9.9 ± 3.6^{a}	5.4 ± 1.2^{c}
DDGS	69.7 ± 1.2	15.4 ± 0.3^{b}	10.0 ± 0. 4^{a}	5.7 ± 0. 4^{b}
Fillet				
Control	78.2 ± 1.2	18.8 ± 0. 6^{b}	1.6 ± 0. 2^{c}	1.4 ± 0.5
CPC	78.5 ± 1.6	18.7 ± 2.8^{b}	1.9 ± 0. 1^{bc}	1.4 ± 0. 4
CGM	77.9 ± 0.8	19.2 ± 2.4^{b}	2.2 ± 0.8^{b}	1.3 ± 0.1
HPDDG	76.2 ± 1.3	19.8 ± 1.2^{a}	2.4 ± 0.5^{b}	1.2 ± 0.7
DDGS	77.2 ± 0.6	18.3 ± 0. 9^{b}	3.08 ± 0.8^{a}	1.3 ± 0.1

Mean values in same row with different superscripts are statistically different ($p < 0.05$)

Table 6 Whole body amino acid composition (g kg^{-1} wet basis) of Nile tilapia fed experimental diets over 12 weeks (Mean ± SD, n=3).

Amino acid	Control	CPC	CGM	HPDDG	DDGS	p value
EAA						
Arginine	10.3 ± 1.2	9.1 ± 0.5	10.2 ± 2.2	10.8 ± 0.1	10.2 ± 1.2	0.747
Histidine	3.4 ± 0.4	2.9 ± 0.1	3.4 ± 0.8	3.4 ± 0.1	3.4 ± 0.5	0.758
Isoleucine	5.1± 0.8	4.4 ± 0.1	5.8 ± 1.3	4.5 ± 0.3	5.4 ± 0.6	0.443
Leucine	11.5 ± 1.4	10.6 ± 0.4	12.4 ± 2.8	11.2 ± 0.5	11.8 ± 1.8	0.695
Lysine	10.2 ± 1.1	9.4 ± 1.3	10.8 ± 2.3	11.0 ±0.1	10.5 ± 1.5	0.774
Methionine	3.5 ± 0.4	3.1 ± 0.2	4.0 ± 0.9	3.2 ± 0.1	3.7 ± 0.4	0.467
Phenylalanine	6.2 ± 0.8	5.2 ± 0.4	6.6 ± 1.4	5.6 ± 0.4	6.4 ± 1.1	0.586
Threonine	7.7 ± 0.9	6.6 ± 0.8	8.1 ± 1.8	7.3 ± 0.5	7.8 ± 1.2	0.690
Tryptophan	1.1±0.2	0.9±0.1	1.1±0.2	1.2±0.4	1.1±0.4	0.742
Valine	6.2 ± 0.9	5.4 ± 0.7	6.8 ± 1.6	5.7 ± 1.4	6.4 ± 0.6	0.537
NEAA						
Alanine	12.2 ± 1.3	10.5 ± 0.4	11.8 ± 2.5	12.8 ± 0.3	11.9 ± 1.6	0.642
Aspartic acid	16.2 ± 1.8	14.2 ± 0.1	13.4 ± 2.6	16.4 ± 0.5	16.3 ± 2.4	0.405
Cysteine	0.8 ± 0.1	0.6 ± 0.2	1.0 ± 0.1	0.6 ± 0.1	0.8 ± 0.2	0.195
Glutamic acid	24.0 ± 2.6	21.0 ± 0.1	24.6 ± 5.3	24.7 ± 0.4	23.8 ± 3.3	0.748
Glycine	15.4 ± 1.9	12.2 ± 1.1	13.4 ± 2.9	15.8 ± 0.6	14.0 ± 1.3	0.334
Serine	7.7 ± 0.9	6.6 ± 0.1	7.9 ± 1.6	7.6 ± 0.2	7.8 ± 1.0	0.688
Taurine	2.1 ± 0.1	2.8 ± 0.8	3.0 ± 0.7	3.8 ± 0.2	2.7 ± 0.1	0.151
Tyrosine	5.0 ± 0.6	4.4 ± 0.4	5.4 ± 1.3	4.4 ± 0.4	5.3 ± 0.8	0.591

Table 7 Body indices of Nile tilapia fed diets containing corn co-products over 12 weeks ((Mean ± SD, n=10)

Morphometry index	Control	CPC	CGM	HPDDG	DDGS
VSI	10.8 ± 0.5	12.8± 1.4	12.1± 0.5	11.6± 0.9	12.9± 1.6
HSI	3 .0 ± 0.2	2 .0 ± 0.8	2 .2 ± 1.4	2.1 ± 0.1	2.7 ± 0.7
FY	30.4 ±2.6	28.3 ±1.1	31.9 ±2.6	30.8 ±1.1	32.4 ±1.9
K	2.0 ± 0.1	1.9 ± 0.1	1.8 ± 0.1	2.0 ± 0.2	2.0 ± 0.1

VSI, viscerosomatic index = 100 x visceral weight (g)/ body weight (g); HSI, hepatosomatic index = 100 x liver weight (g)/body weight (g); FY, fillet yield = 100 x fillet weight (g) /body weight (g) ; K, coefficient of condition = 100 x body weight (g)/ total length $(cm)^3$