Chapter 7
Nutritional Characteristics and Feeding Value of Corn Protein Concentrate in Aquaculture and Layer Diets

Introduction

Historically, fish meal (FM) has been the “gold standard” high crude protein (CP) feed ingredient used in aquaculture diets but its continued used is not sustainable (Naylor et al., 2009). Therefore, finding suitable replacements for FM is essential, and protein concentrates from grains, oilseeds and pulses have generally considered to be attractive alternatives. Unfortunately, using plant-based alternative protein sources, such as corn protein concentrate (CPC) and distillers dried grains with solubles (DDGS), can result in suboptimal growth performance and reduced protein efficiency, especially in carnivorous fish, when fed diets containing low amounts of FM and high amounts of plant-based protein concentrates even though the requirements of all known essential nutrients, including amino acids, appear to be met (Gomes et al., 1995; Davies et al. 1997; Refstie et al., 2000; Martin et al., 2003; Gómez-Requeni et al., 2004). There are several potential reasons for reduced growth performance of fish fed relatively high amounts of plant-based protein sources including reduced feed intake; presence of anti-nutritional factors, anabolic steroids and phytoestrogens; unidentified nutrient deficiencies, and an imbalance of essential amino acids (Gatlin et al. 2007; Glencross et al., 2007; Krogdahl et al., 2010). The most likely cause of suboptimal growth is inadequate amounts of digestible amino acids provided by plant-based protein sources because they are generally lower in lysine (Lys), threonine (Thr), and tryptophan (Trp) than FM, which may cause deficiencies relative to amino acid requirements of fish. To correct these deficiencies, supplemental synthetic amino acids must be added to all diets containing plant-based protein sources including corn co-products such as CPC. In addition, Brezas and Hardy (2020) also suggested that the dynamics of protein digestion for plant-based protein ingredients may vary depending on the synchronization and homogeneity of amino acid digestion and absorption which can ultimately affect growth. Therefore, although there are nutritional challenges for using high protein corn co-products such as CPC in aquaculture diets to achieve optimal growth and fillet composition, some of these challenges may be overcome by supplementing diets with appropriate amounts of synthetic amino acids rather than rely solely on direct substitution of fishmeal without dietary amino acid adjustments.

AAFCO Definition of Corn Protein Concentrate

Corn protein concentrate (CPC) is unique compared with all other corn co-products because it contains the greatest concentration of CP (~ 80%). It is produced using a unique wet milling process compared with the different processes used to produce corn fermented protein (CFP) and high protein distillers dried grains (HP-DDG) in dry grind ethanol facilities. Corn protein concentrate is produced by Cargill Corn Milling facilities in the United States and is marketed under the brand name Empyreal® 75. A modified process has also been used to produce Lysto™, which contains much greater lysine content and improved amino acid profile compared with the process used to produce Empyreal® 75 (Yu et al., 2013). Because of its very high CP content, CPC is of great interest to aquaculture nutritionists due to its potential for partially or completely replacing FM (64% CP) in aquaculture diets while maintaining the high total dietary CP and amino acid concentrations necessary to meet the nutritional requirements of all species of fish. The Association of American Feed Control Officials defines corn protein concentrate as follows:

48.89 Corn Protein Concentrate
"Corn Protein Concentrate is the dried proteinaceous fraction of the corn primarily originating from the endosperm after removal of the majority of the non-protein components by enzymatic solubilization of the protein stream obtained from the wet-milling process. The proteinaceous fraction of the corn must contain not less than 80% protein on a moisture free basis and not more than 1% starch on a moisture free basis. The product must be labeled on "as fed" basis. This fraction shall be free of fermented corn extractives, corn germ meal, and other non-protein components except in such amounts as might occur unavoidably in good manufacturing processes. Vegetable oils or other appropriate ingredients as defined in Section 87 in the Association of American Feed Control Officials Official Publication (AAFCO OP) may be added in concentrations not to exceed 3% to reduce dust during handling. The name of the dust control agent, if used, must be shown as an added ingredient."

Therefore, CPC primarily contains the proteins from the endosperm of corn grain which results in minimal amounts of fiber and ash compared with other corn co-products. Furthermore, unlike CFP, corn protein concentrate contains no residual spent yeast.

Nutrient Profile of Corn Protein Concentrate

There are limited published data on the nutritional profile of CPC, but some commercial nutritional specifications and information on Empyreal® 75 can be obtained online at (https://agripermata.com/brochure/commodity/corn_protein_concentrate/brochure2.pdf). Yu et al. (2013) compared the nutritional composition of two types of CPC with Menhaden FM, dehulled solvent extracted soybean meal (SBM), and corn gluten meal (**Table 1**). Although the CP content of CPC is also much greater than Menhaden FM (64%), corn gluten meal (CGM; 65%), and SBM (50%), it contains relatively low Lys and Trp compared with SBM and FM. Furthermore, CPC and CGM contain extremely high concentrations of leucine (Leu) which interferes with the utilization of isoleucine (Ile), valine (Val), and Trp. A detailed discussion regarding the challenges of managing the amino acid profile imbalances of corn protein from all corn co-products in monogastric animal diets is provided in Chapter 1 of this handbook.

Table 1. Nutrient composition (as-fed basis) of two types of corn protein concentrate and compared with menhaden fish meal (FM), dehulled solvent extracted soybean meal and corn gluten meal (Adapted from Yu et al., 2013)

Measure, %	**Menhaden FM**	**Solvent extracted soybean meal**	**Corn gluten meal**	**Corn protein concentrate Empyreal®[1]**	**Corn protein concentrate Lysto™[1]**
Dry matter	90.61	88.36	91.59	90.16	88.39
Crude protein	64.3	49.9	64.8	79.7	79.8
Ether extract	10.7	1.19	0.46	2.36	2.58
ADF	-	2.83	2.82	9.8	7.5
Ash	15.1	5.34	6.63	0.91	0.91
Indispensible amino acids					

Arg	4.99	3.26	2.03	2.11	2.16
His	2.21	1.16	1.30	2.05	1.40
Ile	3.10	1.86	2.51	2.36	2.99
Leu	5.50	3.36	10.04	10.40	11.95
Lys	6.04	2.81	1.03	1.37	5.66
Met	1.47	0.82	1.45	1.77	1.67
Phe	2.97	2.16	3.88	5.00	4.57
Thr	3.46	1.56	2.02	2.42	2.19
Trp	1.10	NR[2]	0.34	0.55	0.37
Val	4.09	1.78	3.03	2.85	3.29
Dispensable amino acids					
Ala	6.45	1.72	5.32	8.26	6.17
Asp	6.84	6.55	3.72	3.89	4.10
Cys	0.43	0.88	1.10	1.28	1.27
Glu	9.70	9.64	12.89	14.20	14.06
Gly	6.05	1.89	1.79	1.84	1.83
Pro	4.48	2.36	5.82	7.42	6.78
Ser	3.37	1.95	2.97	3.53	2.78
Tyr	2.50	1.49	3.08	3.74	3.75

[1]Cargill Corn Milling, Cargill, Inc., Blair, NE.
[2]Not reported.

Summary of Feeding Trials with Nile Tilapia (*Oreochromis niloticus*)

Most of the published studies conducted with CPC in aquaculture feeds involve feeding Nile tilapia (*Oreochromis niloticus*). One of the initial studies was conducted by Herath et al. (2016a) to determine the effects of totally replacing FM (21.8%) with CPC (19.4%), HP-DDG (33.2%), CGM (23.5%), or DDGS (52.4%) in isonitrogenous diets on growth performance and body composition of juvenile (4.5 g initial average weight) Nile tilapia (*Oreochromis niloticus*) in a 12-week feeding trial. Fish fed the control diet containing 21.8% FM and the 52.4% DDGS diet had the highest specific growth rate, feed intake, protein retention, and survival among all dietary treatments (**Table 2**). In contrast, fish fed the CGM and CPC diets had the lowest specific growth rate, thermal growth rate, feed intake, protein retention, and survival. The reduced protein retention in tilapia fed the CGM and CPC diets was reflected in lower whole body protein content, but not in protein content of fillets (**Table 2**). Whole body lipid content was greater and ash content was lower in fish fed corn co-product diets compared with those fed the control diet. However, no differences were observed for any of the body indices measured. Results from this study indicate that completely replacing fishmeal with various corn co-products in juvenile Nile tilapia diets results in different effects on growth performance and whole body and fillet composition. Among the corn co-products evaluated, diets containing DDGS provided the best growth performance and composition responses while the feeding the CPC diet resulted in the poorest growth performance in diets without FM.

Table 2. Comparison of growth performance, body indices, and fillet color of Nile tilapia (*Oreochromis niloticus*) fed corn co-product diets for 12 weeks (Adapted from Herath et al., 2016a)

Measure	Control	HP-DDG[1]	DDGS[2]	CGM[3]	CPC[4]
Growth performance					
Specific growth rate, %	3.56[a]	3.30[b]	3.53[a]	2.75[c]	2.63[d]
Thermal growth coefficient	1.21[a]	1.06[c]	1.16[b]	0.81[d]	0.76[e]
Feed intake, g dry weight	84.05[a]	71.05[a]	81.20[a]	40.2[b]	38.80[b]
Feed conversion ratio	1.00	1.05	1.05	1.00	1.10
Protein efficiency ratio	3.20	2.99	3.06	3.10	2.84
Protein retention, %	49.62[a]	46.17[ab]	46.70[ab]	42.02[bc]	38.42[c]
Survival, %	100.0[a]	80.6[bc]	97.2[ab]	66.6[c]	75.0[c]
Whole body composition, % wet basis					
Moisture	69.4	68.9	69.7	70.9	71.6
Protein	15.5[b]	16.7[a]	15.4[b]	14.6[c]	13.9[d]
Lipid	8.5[b]	9.9[a]	10.0[a]	9.8[a]	9.6[a]
Ash	6.9[a]	5.4[c]	5.7[b]	4.0[e]	5.0[d]
Fillet composition, % wet basis					
Moisture	78.2	76.2	77.2	77.9	78.5
Protein	18.8[b]	19.8[a]	18.3[b]	19.2[b]	18.7[b]
Lipid	1.6[c]	2.4[b]	3.1[a]	2.2[b]	1.9[bc]
Ash	1.4	1.2	1.3	1.3	1.4
Body indices					
Viscerosomatic index[5]	10.8	11.6	12.9	12.1	12.8
Hepatosomatic index[6]	3.0	2.1	2.7	2.2	2.0
Fillet yield[7], %	30.4	30.8	32.4	31.9	28.3
Coefficient of condition[8]	2.0	2.0	2.0	1.8	1.9

[a,b,c,d,e]Means with uncommon superscripts in each row are different ($P < 0.05$).
[1]HP-DDG = high protein distillers dried grains.
[2]DDGS = distillers dried grains with solubles.
[3]CGM = corn gluten meal.
[4]CPC = corn protein concentrate.
[5]Viscerosomatic index = 100 × visceral weight (g)/body weight (g).
[6]Hepatosomatic index = 100 × liver weight (g)/body weight (g).
[7]Fillet yield = 100 × fillet weight (g)/body weight (g).
[8]Coefficient of condition = 100 × body weight (g)/total length (cm^3).

In a subsequent longer term comparative study, Herath et al. (2016b) evaluated the effects of feeding corn co-product-based diets on growth performance, fillet color and composition of Nile tilapia (*Oreochromis niloticus*) during a 24-week feeding period. In this study, diets consisted of a control diet containing 10% FM, and four other diets without fishmeal but containing HP-DDG (33.2%), DDGS (52.4%), CGM (23.5%), or CPC (19.4%) to replace 50% of the dietary CP. Fish (initial body weight = 21 g) fed the control, HP-DDG, and DDGS diets had greater mean weight gain, specific growth rate, mean feed intake, protein, efficiency ratio and improved feed conversion and survival than those fed CGM and CPC diets (**Table 3**). However, there was no effect of corn co-product on lightness, redness, yellowness, crude protein, and total amino acid content of fillets. Fish fed the CGM diet had the greatest lipid and ash content in fillets, while fillet fatty acid composition varied among dietary treatments. Results from this study indicate that adding HP-DDG or DDGS to non-fishmeal diets at levels up to provide up to 50% of dietary CP has no negative effects on growth performance or fillet color but feeding diets containing CGM and CPC were detrimental to growth performance at these inclusion rates.

Table 3. Comparison of growth performance, body indices, and fillet color of Nile tilapia (*Oreochromis niloticus*) fed corn co-product diets for 24 weeks (Adapted from Herath et al., 2016b)

Measure	Control	HP-DDG	DDGS	CGM	CPC
Growth performance					
Mean weight gain, g	162.2[a]	160.7[a]	161.4[a]	88.3[b]	74.9[b]
Specific growth rate, g	1.27[a]	1.26[a]	1.27[a]	0.96[b]	0.90[b]
Mean feed intake, g	216.2[a]	222.2[a]	225.5[a]	148.8[b]	124.1[b]
Feed conversion ratio	1.33[b]	1.38[b]	1.40[b]	1.72[a]	1.66[a]
Protein efficiency ratio	2.31[a]	2.12[a]	2.30[a]	1.69[b]	1.68[b]
Survival, %	97.2[a]	97.2[a]	97.2[a]	91.7[a]	52.7[b]
Body composition					
Intraperitoneal fat ratio	1.99	2.22	1.50	2.02	1.34
Hepatosomatic index	2.70[b]	2.70[b]	1.93[c]	3.45[a]	2.30[bc]
Viscerosomatic index	9.33	10.92	9.44	11.62	11.50
Fillet yield	28.16	27.52	27.34	27.14	26.37
Condition color	2.01[a]	1.83[c]	1.89[bc]	1.94[b]	1.87[bc]
Fillet color measures					
L*	47.8	48.0	47.8	41.5	41.8
a*	1.3	0.7	1.2	1.8	2.3
b*	3.2	2.3	2.3	1.3	2.2
Chroma[1]	3.5	2.4	2.7	1.9	3.3
Hue angle[2], degrees	67.5	74.0	54.5	53.6	43.3
∆E[3]	0	1.11	0.97	6.61	6.22

[a,b,c]Means with uncommon superscripts in each row are different ($P < 0.05$).
[1]Chroma = intensity of color.
[2]Hue angle = 0° for redness and 90° for yellowness.
[3]∆E = total color difference compared with control.

In contrast to the studies conducted by Herath et al. (2016a,b) where diets containing 19.4% CPC were fed, Khalfia et al. (2017) fed four isocaloric-isonitrogenous diets containing lower inclusion rates (0, 5, 10 and 19%) of CPC as a replacement for FM to Nile tilapia (*Oreochromis niloticus*) fingerlings for 8 weeks. There were no differences in growth performance of fish fed the 5 and 10% CPC diets compared with fish fed the 0% CPC diet, and all of these diets provided better growth performance compared with feeding the 19% CPC diet. Furthermore, there were no differences in fillet yield and body composition among dietary treatments. Interestingly, the stomach size of fish fed the control diet was slightly smaller and the stomach wall was thinner than observed in fish fed the CPC diets when using an electron microscope. Furthermore, feeding the 10 and 19% CPC diets reduced total aerobic bacteria and coliform counts compared with fish fed diets with 0 and 5% CPC diets. Results from this study indicate that up to 10% CPC can be added in tilapia fingerling diets to replace up to 53% FM without any negative effects on growth performance and body composition.

Most recently, Ng et al. (2019) evaluated the effects of replacing fishmeal with CPC on growth performance, nutrient utilization, gut morphology, and skin coloration of red hybrid tilapia (*Oreochromis* sp.). Five isonitrogenous (35% CP) and isolipidic (1% ether extract) diets were formulated to contain CPC that replaced 0, 25, 50, 75, or 100% of FM and were fed to triplicate groups of tilapia (average initial weight = 10.33 g) for 63 days. The results showed that replacing up to 50% FM in red hybrid tilapia diets with CPC had no negative effects on growth rate, feed utilization, haematocrit counts, condition factor, and gut morphology of tilapia, but when CPC replaced 75 or 100% of fishmeal, negative effects were observed. In addition, the carotenoids present in CPC increased skin yellowness in fish fed the diet where CPC replaced 100% of FM. Using regression analysis, the optimal replacement rate of FM by CPC was 25% for percentage weight gain, 33% for FCR and 29% for protein efficiency ratio. Results from this study suggest that CPC can be used as a single plant protein source to substitute up to 50% FM in red hybrid tilapia diets.

Summary of Feeding Trials with Pacific White Shrimp (*Litopenaeus vannamei*)

Three tank feeding trials and a pond production trial were conducted to evaluate the addition of increasing amounts of CPC on growth performance of Pacific white shrimp (*Litopenaeus vannamei*) during various feeding periods (Yu et al., 2013). In the first tank trial, juvenile shrimp (0.52 g average initial weight) were fed diets containing 8% CGM and 6.5 or 13.0% CPC for 6 weeks. The second tank trial involved feeding juvenile shrimp (0.36 g average initial weight) diets containing 0, 4, 8, and 16% CPC and supplemental synthetic L-Lys to replace SBM on an isonitrogenous basis, along with a diet containing 9.7% CPC with an enhanced amino acid profile and greater Lys content as a replacement for CPC and synthetic L-Lys for a 10-week feeding period. The third tank trial involved feeding diets containing 0, 4, 8, and 16% CPC to juvenile shrimp (0.128 g average initial body weight) for a 44-day growth performance trial. Results of the first two trials showed no significant differences in final average weight, weight gain, feed conversion ratio, or survival. At the end of trial two, there were no differences in dry matter and CP of shrimp or differences in protein retention efficiency among dietary levels of CPC. However, results from trial 3 showed reductions in final biomass, final weight, and feed conversion for shrimp fed the 8 and 12% CPC diets compared with those fed the 0 and 4% CPC diets.

In the pond production trial (Yu et al., 2013), juvenile shrimp (0.023 g average initial weight) were placed in 16 production ponds and fed one of four diets containing 0, 4, 8, or 12% CPC for a 16-week feeding period before harvest. As shown in **Table 3**, there were no differences in final weight, yield, feed conversion ratio, survival, and production value of shrimp among dietary treatments. However, feed cost was significant reduced with increasing CPC levels in the diet, resulting in lower feed cost/kg of shrimp for those fed 8 and 12% CPC diets compared with those fed 0 and 4% CPC diets. Results from this study indicate that CPC can be added up to 12% of juvenile Pacific white shrimp diets without affecting growth performance while significantly reducing diet cost/kg of shrimp produced.

Table 3. Growth performance, feed cost, and production value of Pacific white shrimp (*Litopenaeus vannamei*) fed diets containing increasing levels of corn protein concentrate (CPC) for 16 weeks (adapted from Yu et al., 2013)

Measure	0% CPC	4% CPC	8% CPC	12% CPC
Final weight, g	20.51	17.48	17.17	18.71
Yield, kg/ha	5,008	5,190	5,421	5,440
Feed conversion ratio	1.38	1.34	1.27	1.29
Survival, %	64.9	77.6	83.6	75.9
Feed cost, $	791[a]	716[b]	651[c]	598[d]
Feed cost/kg shrimp	1.60[a]	1.39[ab]	1.20[b]	1.11[b]
Production value, $	2,107	1,808	1,844	2,018

[a,b]Means with uncommon superscripts in each row are different ($P < 0.05$).

Summary of Feeding Trails with Laying Hens

One study has been conducted to evaluate the nutritional value of adding CPC to laying hen diets on egg production and egg quality (Herrera et al., 2019). Laying hens (64 weeks of age, 2.05 kg body weight) were fed isocaloric (2,850 kcal/kg) and isonitrogenous (15% CP) diets containing 0, 0.5, 1.0, 1.5, 2.0, or 2.5% CPC for 10 weeks. Quadratic responses were observed for hen body weight gain, feed intake, feed conversion, egg production, egg mass, and egg weight as dietary CPC levels increased. Increasing levels of CPC in layer diets also linearly increased feed intake, feed conversion, shell thickness and breaking strength, and yolk color. However, albumen height and Haugh units were not affected by dietary CPC level. Results from this study indicate that adding up to 2.5% of CPC to laying hen diets improves egg production

Conclusions

Corn protein concentrate is an attractive alternative high protein feed ingredient for use in aquaculture and poultry diets. Limited studies have been conducted to evaluate the addition of CPC to Nile tilapia (*Oreochromis niloticus*) and Pacific white shrimp (*Litopenaeus vannamei*) and indicate that feeding diets containing up to 10% CPC or replacing up to 50% of FM in tilapia diets, and up to 12% in shrimp diets, provides satisfactory growth performance and body and fillet composition. Feeding diets containing up to 2.5% CPC to laying hens has been shown to improve egg production and quality.

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