Chapter 2
Feeding Applications of Corn Fermented Protein Co-Products in Aquaculture Diets

Introduction

Although the use of corn fermented protein (CFP) co-products is extensively promoted in aquaculture diets, it is surprising that there have been only a few published studies. Corn fermented protein co-products are excellent energy and digestible amino acid sources for use in aquaculture diets and have been evaluated as complete or partial replacements for soybean meal and fish meal in diets for European seabass (*Dicentrarchus labrax*), Nile tilapia (*Oreochromis niloticus*), Pacific white shrimp (*Litopenaeus vannamei*), and Atlantic salmon (*Salmo salar*).

Comparison of the Nutrient Profile of Corn Fermented Protein with Common Protein Sources in Aquaculture Diets

Unlike swine and poultry diet formulations, the use of various "high protein" feed ingredients in aquaculture diets is frequently evaluated based on their relative capability of partially replacing common standards of fish meal (FM) and SBM. There are limited comparative energy and amino acid digestibility data for CFP sources relative to SBM and FM for various fish species, but Qui et al. (2017) compared the DM, energy, CP, and amino acid digestibility of a CFP source (NexPro) with SBM and FM fed to Pacific white shrimp (*L. vannamei*). As shown in **Table 1**, DM digestibility of CFP was greater, energy and amino acid digestibility was similar, and protein digestibility was less than FM. Soybean meal had greater DM, CP, energy and amino acid digestibility than CFP and FM. These results suggest that CFP is an acceptable replacement for FM but not SBM in Pacific white shrimp diets.

Table 1. Comparison of proximate analysis, amino acid composition and apparent digestibility of corn fermented protein (CFP) from NexPro, soybean meal (SBM), and fish meal (FM) for Pacific white shrimp (*L. vannamei*; adapted from Qiu et al., 2017)

Analyte, % (as-fed basis)	CFP	SBM	FM
Dry matter	94.77	89.03	92.01
Apparent DM digestibility, %	69.72	78.51	49.15, 49.45
Crude protein	49.20	44.89	62.78
Apparent digestibility of protein, %	60.58	97.03	67.07, 71.3
Crude fat	4.31	3.78	10.56
Crude fiber	4.29	3.20	0.00
Apparent energy digestibility, %	68.09	82.56	69.77, 67.78
Ash	4.87	6.67	18.75
Ala	3.26 (70)	2.04 (94)	3.91 (69)
Arg	3.26 (77)	3.35 (97)	3.68 (75)
Asp	4.05 (73)	5.10 (95)	5.34 (69)
Cys	0.82 (73)	0.62 (91)	0.47 (54)
Glu	7.49 (68)	8.24 (96)	7.47 (71)
Gly	1.54 (73)	2.04 (95)	4.88 (67)

His	1.42 (76)	1.20 (94)	1.63 (74)
Ile	2.18 (71)	2.17 (93)	2.42 (69)
Leu	5.64 (68)	3.57 (92)	4.21 (71)
Lys	2.14 (72)	3.06 (95)	4.67 (77)
Met	0.83 (74)	0.66 (95)	1.61 (71)
Phe	2.89 (69)	2.35 (93)	2.39 (65)
Pro	3.58 (68)	2.39 (95)	3.08 (67)
Ser	2.53 (75)	1.90 (93)	2.11 (58)
Thr	2.02 (73)	1.75 (92)	2.41 (66)
Trp	0.54 (80)	0.62 (95)	0.62 (80)
Tyr	2.34 (74)	1.64 (95)	1.67 (74)
Val	2.73 (72)	2.34 (91)	2.99 (67)

European Seabass (*Dicentrarchus labrax*)

Two studies have been published that evaluated feeding CFP to European seabass (Goda et al., 2019; 2020). In the first study, Goda et al. (2019) conducted an 8-week growth performance trial to determine if increasing levels (30, 40, and 50%) of CFP could be used to partially replace soybean meal in diets for *Dicentrarchus labrax* fingerlings with average initial body wight of 7.5 g/fish. Researchers initially referred to the CFP used in this study as a "high protein DDG source" but later correctly described it as NexPro in the conclusions. Experimental diets were formulated to contain the same crude protein (45%) and crude fat (13%) content. As shown in **Table 2**, fish fed the 30, 40, and 50% CFP diets had improved body weight gain, specific growth rate, and feed intake compared with fish fed the control diet. There was no mortality among dietary treatments and fish fed the 50% CFP diet had improved feed conversion compared with those fed the other treatments. Improvements in hematological, biochemical, total antioxidant capacity, and intestinal morphology measures were observed when fish were fed the CFP diets compared with those fed the control diets, and the authors suggested that these responses may be associated with yeast components present in CFP. Results from this study show that adding up to 50% CFP to partially replace soybean meal in diets for seabass juveniles improves growth performance and may positively affect fish health status.

Table 2. Effects of feeding increasing dietary levels of corn fermented protein (NexPro) to European seabass (*Dicentrarchus labrax*) on growth performance (adapted from Goda et al., 2019)

	Dietary Corn Fermented Protein Inclusion Rate, %			
Measure	**0%**	**30%**	**40%**	**50%**
Initial body weight, g/fish	7.47	7.50	7.50	7.53
Final body weight, g/fish	14.47^{b}	17.20^{a}	17.37^{a}	18.03^{a}
Weight gain, g/fish	7.00^{b}	9.70^{a}	9.87^{a}	10.50^{a}
Specific growth rate, %/day	0.87^{b}	1.39^{a}	1.41^{a}	1.70^{a}
Feed intake, g/fish	11.97^{b}	14.17^{a}	13.30^{a}	13.20^{a}
Feed conversion ratio[2]	1.71^{a}	1.45^{ab}	1.46^{ab}	1.26^{b}
Survival, %	100	100	100	100

[1]Specific growth rate = 100 × [(final body weight (g) – initial body weight (g)/duration of feeding (days)]
[2]Feed conversion ratio= live weight gain (g)/dry feed intake (g).
[a,b]Means without common superscripts within rows are different ($P < 0.05$).

In a subsequent study, Goda et al. (2020) fed diets containing 30, 40, and 50% CFP to partially replace soybean meal (SBM), and supplemented with a commercial protease enzyme, to evaluate growth performance, physiological, and intestinal histology responses in juvenile European seabass. Feeding the 50% CFP diet resulted in increased final body weight, weight gain, specific growth rate, and feed conversion ratio compared with feeding the control, 30% and 40% CFP diets (**Table 3**). These improvements were a result of improved protein efficiency ratio, protein productive value, lipid retention, and energy retention in fish fed the 50% CFP diet compared with those fed the control diet, with improvements also observed in these nutritional efficiency measures when feeding the 30% and 40% CFP diets compared with the control diet (Table 3). There was no fish mortality observed in any of the treatments during the 70-day feeding trial. Similar to the results reported by Goda et al. (2019), feeding the CFP diets supplemented with protease enzyme improved measures of hematology, serum biochemistry, humeral immune responses, and intestinal morphology. These results support the addition of up to 50% CFP in juvenile seabass diets as a partial replacement of SBM to support optimal growth performance and health.

Table 3. Effects of feeding increasing dietary levels of corn fermented protein (NexPro) with protease enzyme supplementation to European seabass (*Dicentrarchus labrax*) on growth performance and nutritional efficiency (adapted from Goda et al., 2020)

	Dietary Corn Fermented Protein Inclusion Rate, %			
Measure	**0%**	**30%**	**40%**	**50%**
Initial body weight, g/fish	7.47	7.53	7.43	7.43
Final body weight, g/fish	15.57^{a}	16.80^{ab}	17.07^{ab}	19.28^{b}
Weight gain, g/fish	8.10^{a}	9.27^{ab}	9.63^{ab}	11.85^{b}
Specific growth rate, %/day	1.31^{a}	1.43^{ab}	1.48^{ab}	1.70^{b}
Feed intake, g/fish	16.93^{a}	15.57^{b}	14.47^{b}	13.07^{c}
Feed conversion ratio[2]	2.09^{a}	1.68^{ab}	1.47^{ab}	1.10^{b}
Survival, %	100	100	100	100
Protein efficiency ratio	1.07^{c}	1.33^{b}	1.48^{b}	1.94^{a}
Protein productive value, %	11.08^{c}	17.33^{b}	19.78^{b}	26.15^{a}
Lipid retention, %	22.42^{c}	26.94^{b}	35.69^{a}	27.82^{b}
Energy retention, %	6.72^{d}	7.80^{cd}	10.20^{a}	8.28^{b}

[1]Specific growth rate = 100 × [(final body weight (g) – initial body weight (g)/duration of feeding (days)]
[2]Feed conversion ratio= live weight gain (g)/dry feed intake (g).
[a,b,c,d]Means without common superscripts within rows are different ($P < 0.05$).

Nile Tilapia (*Oreochromis niloticus*)

There are limited data on the digestibility of various nutrients in CFP co-products for various aquaculture species. However, one study (unpublished) has been conducted to determine the organic matter, gross energy, crude protein, ether extract, and amino acid digestibility of CFP from ProCap Gold when fed to Nile tilapia (*Oreochromis niloticus*), and the digestibility coefficients are shown in **Table 4**.

Table 4. Apparent digestibility (%) of organic matter, gross energy, crude protein, ether extract, and amino acids of two samples of CFP fed to adult Nile tilapia (*O. niloticus*; unpublished data adapted with permission from Marquis ProCap)

Measure, %	**CFP**
Organic matter	60.6
Gross energy	83.1
Crude protein	83.1
Ether extract	52.9
Indispensable amino acids	
Arg	93
His	94
Ile	93
Leu	94
Lys	89
Met	89[a]
Phe	93
Thr	85
Val	92
Dispensable amino acids	
Ala	94
Asp	93
Glu	96
Gly	93[a]
Pro	95
Ser	92
Tyr	92

[a,b]Means without common superscripts within rows are different ($P < 0.05$).

Suehs and Gatlin (2022) conducted a study to determine the nutritional value of CFP (ProCap Gold) on growth performance, body composition, and immune responses of juvenile Nile tilapia (*Oreochromis niloticus*). In the first trial, the control diet was formulated to contain 36% crude protein provided by SBM, soy protein concentrate, and menhaden fish meal (FM). The experimental diets were formulated to partially replace SBM and FM with 7.5, 15, 22.5, 30, or 37.5% CFP, and were supplemented with soybean oil to provide 6% lipid in all diets. Each pelleted diet was fed to groups of 15 juvenile tilapia (10.6 g initial body weight) per aquarium to provide 3 replicates per dietary treatment during the 8-week feeding period. At the end of the 8-week feeding period, 3 fish from each aquarium were selected and humanely euthanized to measure hepatosomatic index, intraperitoneal fat ratio, fillet yield, and fillet composition. Blood samples were also collected to determine several non-specific immune responses including blood neutrophil oxidative radical production, intracellular and extracellular superoxide anion production, lysozyme, total protein, total immunoglobulins, and anti-protease activity. Results showed no differences in growth, gain efficiency, survival, fillet yield (**Table 5**), and body composition (**Table 6**) among dietary treatments. This was expected because all diets were formulated to contain the same protein and energy levels as increasing amounts of CFP was added to partially replace SBM and FM. Furthermore, feeding diets containing up to 37.5% CFP had no effect (data not shown) on any of the non-specific immune measures evaluated in this study.

Table 5. Effects of feeding diets containing 0, 7.5, 15, 22.5, 30, and 37.5% corn fermented protein (ProCap Gold) to juvenile Nile tilapia (*O. niloticus*; initial weight 0.25 g) on growth performance, fillet yield, hepatosomatic index, intraperitoneal fat, and survival during an 8-week feeding period (Suehs and Gatlin, 2022; adapted with permission from Marquis ProCap)

	Dietary Corn Fermented Protein Inclusion Rate, %					
Measure	**0%**	**7.5%**	**15%**	**22.5%**	**30%**	**37.5%**
Increase from initial weight[1], %	383	321	353	376	354	364
Gain:Feed[2]	0.85	0.79	0.82	0.87	0.81	0.83
Fillet yield[3], %	27.2	27.3	28.5	26.1	26.7	26.7
Hepatosomatic index[4], %	3.09	2.73	3.26	2.92	3.30	3.32
Intraperitoneal fat, %	1.10	1.33	0.99	1.13	0.94	1.40
Survival, %	100	97.8	91.1	100	88.9	95.6

[1]Weight gain = (final weight, g – initial weight, g) / initial weight,g × 100.
[2]Gain:Feed = weight gain, g / dry feed offered, g.
[3]Fillet yield = fillet weight, g / 100 g body weight.
[4]Hepatosomatic index = (100 × liver weight, g / body weight, g).
[5]Intraperitoneal fat, % = (intraperitoneal fat weight, g / body weight, g × 100).

Table 6. Whole body composition of juvenile Nile tilapia (*O. niloticus*) fed diets containing 0, 7.5, 15, 22.5, 30, and 37.5% corn fermented protein (ProCap Gold) after an 8-week feeding period (Suehs and Gatling, 2022; adapted with permission from Marquis ProCap)

	Dietary Corn Fermented Protein Inclusion Rate, %					
Measure	**0%**	**7.5%**	**15%**	**22.5**	**30%**	**37.5%**
Moisture, %	70.9	72.9	70.9	70.8	71.4	69.9
Protein, %	17.5	16.8	17.4	17.2	17.2	17.4
Lipid, %	7.4	6.5	7.4	7.8	7.0	8.3
Ash, %	3.8	3.7	3.7	3.9	3.9	3.9
Protein conversion efficiency, %	44.2	40.0	42.4	43.4	40.1	42.5

An unpublished study conducted at Auburn University evaluated the addition of CFP (NexPro) at increasing diet inclusion rates (0, 3.15, 6.30, 9.45, and 12.60%) as a partial replacement for corn protein concentrate (CPC) in diets for juvenile Nile tilapia (7.5 g initial body weight) on growth performance during a 9-week feeding period. There were no significant differences in weight gain, feed conversion, and survival, indicating that up to 12.6% CFP can effectively replace CPC in juvenile tilapia diets without compromising growth performance (**Table 7**).

Table 7. Effects of feeding diets containing 0, 3.15, 6.30, 9.45, and 12.60%) corn fermented protein (NexPro) to juvenile Nile tilapia (*O. niloticus*) on growth performance during a 9-week feeding period (adapted from unpublished research from Auburn University with permission from POET)

	Dietary Corn Fermented Protein Inclusion Rate, %				
Measure	**0%**	**3.15%**	**6.30%**	**9.45%**	**12.60%**
Final mean weight, g	80.4	73.1	79.8	79.5	79.5
Final biomass, g	1,446	1,405	1,436	1,447	1,447
Weight gain[1], %	965	880	953	954	936
Feed conversion ratio[2]	1.23	1.30	1.24	1.23	1.24

Survival, %	90.0	96.3	90.0	91.3	92.5

[1]Weight gain = (final weight – initial weight)/initial weight × 100.
[2]Feed conversion ratio = feed offered/ (final weight – initial weight).

Pacific White Shrimp (*Litopenaeus vannamei*)

Qui et al. (2017) conducted three growth performance trials to evaluate the addition of increasing amounts of CFP (NexPro) as a replacement for SBM or a combination of FM and SBM in practical diets for juvenile Pacific white shrimp (*Litopeneaus vannamei*). In trial 1, shrimp (0.18 g initial body weight; 10 shrimp/tank) were fed diets containing 0, 10, 20, or 30% CFP as a replacement for SBM during a 6-week feeding period. No significant differences in growth rate or feed conversion were observed among dietary treatments (**Table 8**). However, in trial 2, partially replacing portions of SBM and FM in the diets with the addition of 10, 20, or 30% CFP resulted in a reduction in final weight, weight gain, and poorer feed conversion when shrimp were fed the diets containing 20% and 30% CFP compared with those fed the control (0%) and 10% CFP diets (**Table 9**). As a result, a third trial was conducted to determine the maximum inclusion rate of CFP in diets for juvenile shrimp to support optimal growth performance (**Table 10**) and effects on whole body composition (Table 7). Based on these growth performance results, an upper limit of 18% CFP was recommended for juvenile shrimp diets due to reduced weight gain and feed conversion when 24% CFP diets were fed. The reduction in growth performance observed at the higher inclusion rates was likely due to lower energy (68%) and protein (61%) digestibility in CFP compared with SBM (83% and 97%, respectively), and lower in protein digestibility than FM (67 to 71%). In fact, apparent digestibility of several amino acids was lower in CFP compared with SBM (see details in Chapter 1). There were no differences in shrimp whole body composition for moisture, protein, lipid, ash, and macro and trace minerals except for increased iron and copper at the 18% and 24% diet inclusion rates compared to feeding the control diet (**Table 11**). These results suggest that the bioavailability of iron and copper in CFP is relatively high compared with other ingredients used in these diets.

In summary, the results of these three trials indicate that CFP is a good plant-based protein source that can be added up to 30% of juvenile Pacific white shrimp (*Litopeneaus vannamei*) diets to replace SBM, or up to 18% to replace a combination of SBM and FM without negatively affecting growth performance. However, energy and amino acid digestibility of the CFP source evaluated in this study was less than in SBM.

Table 8. Effects of feeding diets containing 0, 10, 20, and 30% corn fermented protein (NexPro) to juvenile shrimp (*L. vannamei*; initial weight 0.18 g) on growth performance during a 6-week feeding period in trial 1 (adapted from Qui et al., 2017)

	Dietary Corn Fermented Protein Inclusion Rate, %			
Measure	**0%**	**10%**	**20%**	**30%**
Final mean weight, g	3.4	3.5	3.1	3.1
Final biomass, g	28.0	31.7	29.0	29.4
Weight gain[1], %	1,724.4	1,894.9	1,679.8	1,827.8
Feed conversion ratio[2]	2.44	2.35	2.62	2.58
Survival, %	84.0	92.0	94.0	94.0

[1]Weight gain = (final weight – initial weight)/initial weight × 100%
[2]Feed conversion ratio = feed offered/ (final weight – initial weight).

Table 9. Effects of feeding diets containing 0, 10, 20, and 30% corn fermented protein (NexPro) to juvenile shrimp (*L. vannamei*; initial weight 1.24 g) on growth performance during a 7-week feeding period in trial 2 (adapted from Qui et al., 2017)

Measure	Dietary Corn Fermented Protein Inclusion Rate, %			
	0%	10%	20%	30%
Final mean weight, g	9.9[a]	9.2[a]	8.0[b]	7.7[b]
Final biomass, g	225.8	204.6	191.4	199.0
Weight gain[1], %	684.8[a]	644.7[ab]	554.9[bc]	519.4[c]
Feed conversion ratio[2]	1.61[a]	1.72[a]	2.05[b]	2.12[b]
Survival, %	76.7	73.3	80.0	85.8

[1]Weight gain = (final weight – initial weight)/initial weight × 100%

[2]Feed conversion ratio = feed offered/ (final weight – initial weight).

[a,b,c]Means without common superscripts within rows are different ($P < 0.05$).

Table 10. Effects of feeding diets containing 0, 6, 12, 18, and 24% corn fermented protein (NexPro) to juvenile shrimp (*L. vannamei*; initial weight 0.25 g) on growth performance during a 6-week feeding period in trial 3 (adapted from Qui et al., 2017)

Measure	Dietary Corn Fermented Protein Inclusion Rate, %				
	0%	6%	12%	18%	24%
Final mean weight, g	5.1[ab]	5.4[a]	5.1[a]	4.6[ab]	4.3[b]
Final biomass, g	41.9	46.8	46.2	41.5	37.6
Weight gain[1], %	1,837.7[ab]	2,065.7[a]	1,854,2[ab]	1,776.2[ab]	1,593.5[b]
Feed conversion ratio[2]	1.81[b]	1.67[b]	1.74[b]	1.94[ab]	2.14[a]
Survival, %	82.5	87.5	90.0	90.0	87.5

[1]Weight gain = (final weight – initial weight)/initial weight × 100%

[2]Feed conversion ratio = feed offered/ (final weight – initial weight).

[a,b]Means without common superscripts within rows are different ($P < 0.05$).

Table 11. Whole body composition of juvenile shrimp (*L. vannamei*; initial weight 0.25 g) fed diets containing 0, 6, 12, 18, and 24% corn fermented protein (NexPro) during a 6-week feeding period in trial 3 (adapted from Qui et al., 2017)

Measure	Dietary Corn Fermented Protein Inclusion Rate, %				
	0%	6%	12%	18%	24%
Moisture, %	77.98	77.45	77.40	76.64	75.90
Protein, %	75.18	73.00	72.60	73.90	73.90
Lipid, %	5.62	5.88	6.81	6.29	6.92
Ash, %	11.43	11.70	11.58	11.70	11.55
Calcium, %	2.97	3.33	3.09	3.41	3.40
Phosphorus, %	1.08	1.06	1.01	1.03	1.02
Sodium, %	1.06	1.15	1.10	1.10	1.09

Potassium, %	1.38	1.45	1.41	1.39	1.38
Sulfur, %	0.87	0.90	0.88	0.88	0.88
Magnesium, %	0.26	0.29	0.27	0.29	0.28
Iron, mg/kg	13.53^{b}	16.40^{ab}	16.05^{ab}	15.70^{ab}	18.68^{a}
Copper, mg/kg	66.53^{c}	69.68^{bc}	73.93^{abc}	84.85^{a}	80.58^{ab}
Zinc, mg/kg	73.28	76.13	74.18	75.13	75.48
Manganese, mg/kg	2.23	3.55	2.75	3.20	3.90

^{a,b,c} Means without common superscripts within rows are different ($P < 0.05$).

Guo et al. (2019) also conducted a study to evaluate the addition of increasing dietary levels of CFP (NexPro) to replace CPC or FM in diets for juvenile Pacific white shrimp (initial weight = 0.36 g) for an 8-week growth performance trial. As shown in **Table 12**, there were no differences in mean weight, weight gain, feed:gain, and survival among all dietary treatments. However, replacing FM with 20% CFP reduced final biomass and reduced feed conversion compared with feeding diets containing 0 or 10% CFP. These results indicate that CFP is a good protein source for Pacific white shrimp and can replace up to 20% of CPC, or up to 15% FM without compromising growth performance.

Table 12. Growth performance and survival responses of juvenile Pacific white shrimp fed increasing dietary levels of corn fermented protein (CFP; NexPro) to partially replace corn protein concentrate (CPC) or fish meal (FM) during a 56-day feeding period (adapted from Guo et al., 2019)

Measure	Diet type							
	CPC	CPC	CPC	CPC	FM	FM	FM	FM
	0% CFP	10%CFP	15% CFP	20% CFP	0% CFP	10% CFP	15% CFP	20% CFP
Biomass, g	225	227	230	221	240^{b}	235^{b}	230^{ab}	216^{a}
Mean weight, g	7.49	7.64	7.88	7.50	8.05	7.90	7.88	7.38
Weight gain, g	7.13	7,28	7.52	7.14	7.68	7.54	7.52	7.02
Weight gain, %	1,997	2,032	2,106	1,996	2,104	2,093	2,106	1,920
Feed:gain	1.5	1.5	1.5	1.5	1.4^{a}	1.4^{a}	1.5^{ab}	1.6^{b}
Survival, %	100.0	99.2	97.5	98.3	99.2	99.2	97.5	97.5

^{a,b}Means without common superscripts within rows are different ($P < 0.05$).

Atlantic Salmon (*Salmo salar*)

Burton et al. (2021) conducted a 12-week feeding trial to evaluate the effects of partially replacing SBM with increasing amounts (0, 5, 10, 15, and 20%) of CFP in Atlantic salmon (initial body weight = 304 g; 5 fish/tank) diets on growth performance, dietary protein utilization, and greenhouse gas (GHG) emissions. Specific details regarding diet composition and formulation were not provided beyond the percentage of SBM replaced in the diets, which was 0, 12.9, 25.8, 37.9, and 50.8% for 0, 5, 10, 15, and 20% inclusion rates of CFP (NexPro), respectively. Fish fed the 10% CFP diet had greater final body weight and feed intake compared with fish fed the 20% CFP diet (**Table 13**). However, there were no differences in feed conversion and protein deposition among dietary CFP inclusion rates.

Table 13. Effects of feeding diets containing 0, 5, 10, 15, and 20% corn fermented protein (NexPro) as a partial replacement for soybean meal to Atlantic salmon (initial weight = 304 g) on growth performance during a 12-week feeding period (adapted from Burton et al., 2021)

	Dietary Corn Fermented Protein Inclusion Rate, %

Measure	0%	5%	10%	15%	20%
Initial body weight, g	295.0	301.9	305.7	304.7	305.0
Final body weight, g	720.0[ab]	701.1[ab]	752.1[a]	690.8[ab]	663.7[b]
Weight gain, g	425.0	399.2	446.4	386.1	358.7
Feed intake/fish, g	411.9[a]	370.5[ab]	414.4[a]	377.8[ab]	348.3[b]
Feed conversion ratio	0.98	0.93	0.93	0.97	0.97
Protein deposition, %	19.8	23.1	23.0	22.1	26.0

[a,b] Means without common superscripts within rows are different ($P < 0.05$).

Feeding increasing dietary levels of CFP had no effect on whole-body dry matter, protein, amino acids (data not shown), lipid, and ash content, nor was there an effect on protein and deposition rate and retention efficiency (**Table 13**). Dietary levels of CFP had no effect on fillet darkness, yellowness, and redness of color in the anterior fillets, and redness and yellowness of color in the posterior fillets, with significant but minor differences in darkness of color (**Table 14**). There were no differences in most blood biochemistry measures except for increases in plasma P and Mg, which may reflect high digestibility in CFP. Total cell count and packed cell volume also increased as CFP inclusion rates increased (data not shown). Creatine kinase is an indicator of tissue inflammation and concentrations were similar across dietary treatments. Histological evaluation showed no evidence of intestinal enteritis and other intestinal disorders, with the majority of distal intestinal samples showing not inflammation of the lamina propria and submucosa (data not shown). These results suggest that CFP is a good protein and energy source in diets for post-smolt Atlantic salmon (*Salmo salar*), and provides similar whole-body composition, protein and lipid utilization, fillet pigmentation, and intestinal histology. However, growth performance may be reduced when adding more than 15% CFP to salmon diets.

Table 14. Effects of feeding diets containing 0, 5, 10, 15, and 20% corn fermented protein (NexPro) as a partial replacement for soybean meal to Atlantic salmon (*Salmo salar*; initial weight = 304 g) on whole body composition, nutrient deposition, and retention rates after a 12-week feeding period (adapted from unpublished data from The Center for Aquaculture Technologies, 2019, provided with permission from POET)

Measure	Dietary Corn Fermented Protein Inclusion Rate, %				
	0%	5%	10%	15%	20%
Dry matter, %	37.1	37.2	38.0	37.8	37.0
Protein, %	18.8	18.4	18.5	18.7	19.0
Protein deposition rate, mg/°C-d	45.4	41.4	47.6	41.1	41.1
Protein retention efficiency, %	19.8	23.1	23.0	22.1	26.0
Lipid, %	17.1	17.5	18.4	18.0	16.8
Lipid deposition rate, mg/°C-d	50.7	50.7	62.6	51.9	43.3
Lipid retention efficiency, %	59.0	50.4	58.7	54.5	50.5
Ash	1.7	1.7	1.8	1.8	1.8
Colorimetric indices					
Anterior filler					
L*	60.0	56.5	56.9	56.3	56.0
a*	7.9	8.0	7.7	7.9	7.9
b*	17.2	17.5	17.2	17.2	17.0
Posterior fillet					
L*	54.9[ab]	54.7[b]	55.5[ab]	55.7[a]	54.6[b]
a*	9.1	9.6	9.1	9.2	9.5

b*	18.8	19.1	18.8	18.6	18.5

[a,b]Means without common superscripts within rows are different (P < 0.05).

Another study was conducted at the University of Idaho Aquaculture Research Institute's Hagerman Fish Culture Experiment Station to determine the nutritional value of CFP (ProCap Gold) on juvenile Atlantic salmon growth performance. Diets were formulated to contain 43% CP and 20% crude lipid. The SBM concentration in the control diet was 22% and was progressively replaced by increasing amounts of CFP resulting in five treatment diets consisting of Diet 1 (22% SBM and 0% CFP); Diet 2 (16.5% SBM and 5.5% CFP); Diet 3 (11.0% SBM and 10.9% CFP); Diet 4 (5.5% SBM and 16.4% CFP); and Diet 5 (0% SBM and 21.9% CFP). Atlantic salmon with an initial body weight of 21 g were fed their respective dietary treatments to satiety for 12 weeks. At study conclusion, survival was 100% across all treatment groups and no statistically significant differences were observed for growth performance measures with increasing dietary CFP inclusion rates (**Table 15**).

Table 15. Effects of feeding increasing dietary levels of corn fermented protein (ProCap Gold) to Atlantic salmon (*Salmo salar*) on growth performance (adapted from unpublished research from the University of Idaho, 2022)

	Dietary Corn Fermented Protein Inclusion Rate, %				
Measure	**0%**	**5.5%**	**10.9%**	**16.4%**	**21.9%**
Initial body weight, g/fish	21.4	21.5	21.5	21.6	21.4
Final body weight, g/fish	169.4	165.3	161.6	168.6	165.2
Weight gain, %	691.1	668.9	653.6	682.3	673.0
Specific growth rate, %/day	2.47	2.42	2.40	2.45	2.43
Feed intake, g/fish	147.1	143.3	142.6	150.8	146.3
Feed conversion ratio	1.00	0.99	1.02	1.03	1.02
Survival, %	100	100	100	100	100

Increasing levels of CFP in the salmon diets resulted in significantly improved dietary lipid digestibility but had no effect on dietary dry matter, CP, or energy digestibility (**Table 16**). These results are supported by high lipid digestibility (97.2%) of CFP (ProCap Gold) fed to Atlantic salmon. Dry matter, CP, and energy digestibility of CFP were 67.5%, 88.7%, and 76.8%, respectively. These results show that CFP is a highly digestible ingredient that can be fed to Atlantic salmon juveniles at levels up to 22% of the diet with no impact on growth performance and survival.

Table 15. Differences in apparent digestibility coefficients (%) for dry matter, protein, lipid, and energy of the experimental diets with increasing dietary levels of corn fermented protein (ProCap Gold) fed to Atlantic salmon (*Salmo salar*) (adapted from unpublished research from the University of Idaho, 2022)

	Dietary Corn Fermented Protein Inclusion Rate, %				
Measure	**0%**	**5.5%**	**10.9%**	**16.4%**	**21.9%**
Dry Matter	69.9	68.3	69.1	69.7	69.8
Protein	88.3	87.5	87.3	87.6	87.4
Lipid	95.7[a]	95.9[ab]	96.7[bc]	97.5[c]	97.3[c]
Energy	78.6	78.2	78.1	78.4	78.5

[a,b,c]Means (n = 3) without common superscripts within rows are statistically different (P<0.05).

Conclusions

Feeding diets containing up to 50% CFP to partially replace SBM in diets for European seabass (*Dicentrarchus labrax*) juveniles improves growth performance and may positively affect fish health status. Diets containing up to 37.5% CFP can provide optimum growth performance and fillet composition for Nile tilapia (*Oreochromis niloticus*). Corn fermented protein is a good plant-based protein source that can be added up to 30% of juvenile Pacific white shrimp (*Litopeneaus vannamei*) diets to replace SBM, or up to 18% to replace a combination of SBM and FM without negatively affecting growth performance. However, energy and amino acid digestibility of CFP sources can be variable and sometimes less than in SBM. Although growth responses from two growth performance suggest different maximum dietary inclusion rates of CFP for Atlantic salmon, results from one study indicates that diets containing up to 22% CFP can be fed without compromising growth rate and feed intake.

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