Digestibility and growth performance of corn protein concentrates added to the diet of Atlantic salmon (Salmo salar)

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INTRODUCTION

Atlantic salmon (Salmo salar) is an important cultured carnivorous species that previously has not had high levels of plant protein feed ingredients included in the diet (Gatlin et al. 2007). The inclusion of plant protein sources in aquafeeds is now competitive due to the high cost of fishmeal resulting from the the demands for animal feeds and other uses of this finite resource (Glenncross et al. 2005; Gatlin et al. 2007). Canola protein concentrate (CPC), soybean meal and soy protein concentrate (SPC), pea protein concentrate, barley protein concentrate (BPC), rice protein concentrate and wheat gluten meal have all been tested as fishmeal replacements with varying degrees of success in different salmonids (Forster et al. 1999, Thiessen et al. 2003, Barrows et al. 2007, Lim and Webster 2008, Gaylord and Barrows 2009). Many of these same protein sources have been tested in Atlantic salmon (Lim and Webster 2008). Atlantic salmon was show to have slightly reduced, but not significantly lower, performance when fed diets that were fishmeal free and contained wheat gluten, corn gluten, fish solubles, and crystalline amino acids (Espe et al. 2006). Atlantic salmon fed a diet that contained 12% fishmeal had slightly decreased growth compared to salmon fed a fishmeal reference diet (containing 56% fishmeal), but produced 2 kg of fish for every 1 kg of fishmeal consumed (Torstensen et al. 2008). Amino acid supplementation is often needed to maintain growth performance of fish fed plant protein-based feeds (Espe et al. 2007, Lim and Webster 2008, Gaylord and Barrows 2009). The challenge for feed cost reduction and efficiency is to increase the amount of plant or other non-animal protein in the diet of carnivorous fishes while maintaining acceptable growth, feed conversion and production costs compared to traditional diets.

Recently multiple studies have reported on digestibility of various plant feed ingredients by Atlantic salmon (Salmo salar) (Storebakken et al. 2000a, Glenncross et al. 2004a, Refstie et al.2005, Aas et al. 2006, Aslaksen et al. 2007, Refstie et al. 2008, Burr et al. 2011). The protein digestibility was not significantly lower for most plant feed ingredients, including meals, protein concentrates and protein isolates; except for extracted soybean, oat, canola, and sunflower meals. This indicates that the majority plant protein sources could be effective feed ingredients, especially protein concentrates, for use in aquafeeds.

The purpose of this study was to determine the growth performance of juvenile Atlantic salmon fed diets containing 15% Emyreal-75 1, Empyreal-75 2, Lysto (corn protein concentrates) or corn gluten meal and the apparent digestibility coefficients of these diets.

METHODS AND MATERIALS

Experimental Feeds Formulation: Experimental diets were formulated to satisfy the nutritional requirements of Atlantic salmon. The feeding trial for growth and digestibility will consist of 5 diets (reference, Empyreal 75-1, Empyreal 75-2, Lysto, and CGM) (Table 1). The diets were produced at the Fish

Technology Center in Bozeman, MT and Kansas State University in Manhattan, KS using commercial manufacturing methods. All ingredients were ground to a particle size of <200µm using an air-swept pulverizer. The diets were processed using a twin-screw cooking extruder with a ~25 sec exposure to 127oC in the extruder barrel (average across 5 sections). Pellets were dried with a pulse bed drier for 20 minutes at 102ºC with a 10 minute cooling period, resulting in final moisture levels less than 10%. All oil was top-coated after the pellets were cooled using a vacuum-coater. Diets were stored in plastic lined paper bags at room temperature and fed within four months of manufacture.

Feeding trial: Eighteen ~0.26 m3 tanks were stocked with a total of 288 Atlantic salmon (Salar salmo) smolts (average initial weight 209 g) (18 fish/tank) at the USDA ARS National Cold Water Marine Aquaculture Center in Franklin, ME. The initial fish stocking density was 14.5 kg/m3. The tanks were supplied with 4-L min-1 of oxygen saturated well water at a temperature of 13°C to14°C from a recirculating biological filtration system (~15 ppt salinity seawater). Dissolved oxygen and temperature were monitored continually and ammonia, nitrite, nitrate, carbon dioxide, and pH will be monitored weekly to insure optimal water quality conditions. Fish were fed the test diets for a 1 week acclimation period prior to the start of the proposed 16 week experimental diet study. Diet were fed to three replicate tanks for the control and corn gluten diets and fed to four replicate tanks for the remaining test diets. A photoperiod of 14L:10D was maintained during the study using artificial lighting. Fish were fed using automatic feeders such that feed is supplied at 100% of maximum expected intake. Each tank was hand fed to satiation once daily to insure that fish are being fed to apparent satiation. Fish in each tank were be bulk-weighed and counted every four weeks during trial with specific growth rate (SGR), feed conversion ratio (FCR), average weight, average weight gain, percent increase calculated at the final weighing.

Digestibility Trial: A digestibility study was conducted at the termination of the growth trial using ~600 g Atlantic salmon at the USDA ARS National Cold Water Marine Aquaculture Center in Franklin, ME. Fish from the growth study were maintained in the same replicate tanks in the growth study and supplied with 4-L min-1 of oxygen saturated water at a temperature of 13°C to14°C from a recirculating biological filtration system (2.0-3.0 ppt salinity). The fish were manually stripped of feces and the feces from each tank pooled until enough dried feces is obtained to weigh 5g, which usually was obtained in 2 to 3 strippings. The fish were allowed to recover for three days between fecal collections. The feces and diets were analyzed for ash, moisture, crude lipid content, crude protein content and lysine content. The methods of Cho et al. (1982) and Bureau et al. (1999) were used to estimate apparent digestibility coefficients (ADCs). Yttrium oxide served as the inert maker. Apparent digestibility coefficients of each nutrient in each diet were calculated according to the following equation (Kleiber 1961, Forster 1999):

$$ADCN_{diet} = 100\text{-}100 \left\{ \frac{\%\ Yt\ in\ diet}{\%\ Yt\ in\ feces} \times \frac{\%\ nutrient\ in\ feces}{\%\ nutrient\ in\ diet} \right\}$$

Samples were sent to the University of Idaho's Holm Research Center, a certified analytical laboratory, for mineral analysis. Samples were also sent to University of Missouri central laboratory for lysine analysis.

RESULTS

The performance of Atlantic salmon fed the reference or experimental diets did not vary over the 16-week feeding trial (Table 2). The final stocking density ranged from a low of 37.7 kg/m3 to a high of 45.9 kg/m3, with an average density of 41.3 kg/m3. The stocking densities in this study are similar to what a commercial producer would have in tanks or net pens (~40kg/m3). Overall weight gain and final weight did not vary among treatments (P = 0.81, 0.83) with fish fed the Empyreal 75-1 diet having the greatest weight gain (409 g gained, 617 g final weight) and fish fed the Empyreal 75-2 diet having the lowest weight gain (383 g gained, 592 g final weight). Specific growth rate was not significantly different among the treatments (p = 0.79) and ranged from a high 0.90%/day to a low of 0.86%/day. Feed conversion ratio (g fed/ g gained) ranged from 1.09 to 1.01 and was not significantly different among the treatments (p = 0.41).

The proximate composition of the fish did notsignificantly vary among the diets (Table 3). Protein levels ranged from 19.1% to 20.0% (p=0.96), lipid levels from 11.8% to 13.1% (0.90), moisture levels from 66.3% to 67.8% (p = 0.56), ash levels 1.6% to 2.1% (0.19) and energy levels 8.6 MJ/kg to 9.1 MJ/kg (p = 0.69). The fish fed the corn gluten meal diet had the highest protein, ash and lipid levels, fish fed the Lysto diet had the highest energy level and the fish fed the reference diet had the highest moisture level. There was not a single diet that had the highest or lowest levels of any macronutrient.

The apparent digestibility coefficient (ADC) values did not significantly among the treatments as shown in table 4 (p values < 0.05). Protein ADC values averaged 91.3% (90.7%-91.7%), lipid ADC values averaged 95.5% (95.0%-96.2%), energy ADC values averaged 87.1% (86.3%-87.7%), organic matter ADC values averaged 86.7% (86.4%-87.1%) and lysine ADC values averaged 96.8% (96.3%-97.2%).

DISCUSSION AND CONCLUSION

The inclusion of 15% corn protein products in the diet did not affect the growth performance, nutrient digestibility or proximate composition of Atlantic salmon compared to salmon fed a fishmeal reference diet. In a previous Atlantic salmon study, corn gluten meal has been shown to have good protein, organic matter and energy ADC values similar to those reported for fishmeal (Burr et al. 2011). When corn gluten meal was included in the diet above 20%, salmon had significantly lower growth compared to a fishmeal reference diet (Mundheim et al. 2004). The reason for this decrease in reported growth was not readily apparent, but might be due to amino acid composition, the presence of antinutritional factors, or palatability in the corn gluten meal.

Atlantic salmon have been fed a variety of plant protein concentrates. Fish fed potato protein concentrate (included up to 21% of the diet) and soy protein concentrate (included at 19.7% of the diet) grew similarly to Atlantic salmon fed fishmeal based diets (Refstie et al., 2001, Refstie and Tiekstra, 2005). Atlantic salmon smolts fed pea protein concentrate, include in the diet at 20%, had similar growth compared to salmon fed a fishmeal diet (Øverland et al., 2009). Atlantic salmon fed a diet that included 50% soy protein concentrate did not have stunted growth compared to fish fed a fishmeal diet (Storebakken et al., 2000b). Growth of Atlantic salmon was inhibited by increasing plant proteins (full-fat soybean meal and corn gluten meal) up to 42% of the diet compared to a fish meal based diet (Kraugerud et al., 2007). We observed similar findings with the present study, indicating that 15% inclusion levels for corn gluten meal, or the corn protein concentrates do not hinder performance of Atlantic salmon. These previous studies indicate that a certain level of plant proteins are tolerated in the diets of Atlantic salmon, but when the threshold is exceeded either antinutritional factors or digestibility of the plant proteins hinder the intake or uptake of nutrients and limit growth.

In conclusion dietary inclusion of 15% of both Empyreal corn protein concentrates; corn gluten meal or Lysto corn protein concentrate will not affect Atlantic salmon performance. Atlantic salmon growth, ADC values for lysine and macronutrients and proximate composition are all similar to a salmon fed a fishmeal reference diet. Future studies looking at fish performance fed diets with increased inclusion levels of corn protein concentrates (at 20%) and the effect on the fillet coloration will be completed in the summer of 2013.

Diet Formulations (g/kg)					
Ingredient	Empyreal 75-1	Empyreal 75-2	Lysto	Corn gluten	Reference
Poultry meal, IDF	176.8	176.8	176.8	176.8	275.0
Fish oil, menhaden	220.1	220.1	220.1	220.1	210.0
Daybrook LT menhaden	200.0	200.0	200.0	200.0	200.0
Wheat flour	150.0	150.0	150.0	110.5	150.0
Empyreal75-1	150.0	0.0	0.0	0.0	0.0
Empyreal75-2	0.0	150.0	0.0	0.0	0.0
CPC Lysto	0.0	0.0	150.0	0.0	0.0
Corn gluten meal, Cargill 2012	0.0	0.0	0.0	187.5	0.0
Soy protein concentrate	43.0	43.0	50.0	43.0	94.0
Wheat gluten meal	32.1	32.1	32.1	32.1	50.0
Vitamin premix ARS 702	10.0	10.0	10.0	10.0	10.0
Lysine-HCl	7.0	7.0	0.0	9.0	0.0
Choline CL	6.0	6.0	6.0	6.0	6.0
Stay-C	2.0	2.0	2.0	2.0	2.0
Trace mineral premix	1.0	1.0	1.0	1.0	1.0
Astaxanthin	1.0	1.0	1.0	1.0	1.0
Yttrium oxide	1.0	1.0	1.0	1.0	1.0
Analysis, analyzed					
Crude protein (g/kg)	454.8	455.9	440.1	451.3	444.4
Crude lipid (g/kg)	262.0	246.5	262.6	259.5	265.0
Moisture (g/kg)	45.3	46.9	44.5	39.4	44.5
Energy (MJ/kg)	22.93	22.88	23.08	23.28	22.70
Ash (g/kg)	64.3	65.4	66.6	64.7	71.9

Table 1.

Growth performance of juvenile Atlantic salmon (means ± S.E.)					
Diet	Final avg weight (g)	Final avg weight gain (g)	Percent increase	SGR	FCR
Empyreal 75-1	617.29 ± 13.86	409.03 ± 13.70	196.38 ± 6.77	0.90 ± 0.02	1.01 ± 0.02
Empyreal 75-2	591.81 ± 24.22	382.68 ± 24.38	182.99 ± 11.80	0.86 ± 0.03	1.07 ± 0.04
Lysto	605.86 ± 9.19	397.70 ± 9.36	191.06 ± 4.67	0.88 ± 0.01	1.08 ± 0.02
Corn Gluten	593.58 ± 26.22	384.93 ± 26.54	182.18 ± 12.77	0.86 ± 0.04	1.09 ± 0.05
Reference	610.50 ± 12.29	401.87 ± 12.39	192.63 ± 6.06	0.89 ± 0.02	1.04 ± 0.02
P Value	0.8235	0.8127	0.7373	0.7852	0.4059

Table 2.

Proximate composition of whole Atlantic salmon (means ± S.E.)						
Diet	% lipid	% moisture	% ash	% protein	Energy (MJ/kg)	% dry matter
Empyreal 75-1	11.80 ± 1.13	67.32 ± 0.84	1.64 ± 0.10	19.09 ± 1.43	8.67 ± 0.18	32.68 ± 0.84
Empyreal 75-2	12.26 ± 0.19	66.43 ± 0.65	1.67 ± 0.10	19.25 ± 1.01	8.92 ± 0.18	33.57 ± 0.65
Lysto	12.84 ± 0.65	66.26 ± 0.54	1.82 ± 0.12	19.52 ± 0.50	9.09 ± 0.15	33.74 ± 0.54
Corn Gluten	13.12 ± 1.83	66.18 ± 1.16	2.14 ± 0.30	19.95 ± 0.78	8.90 ± 0.47	33.82 ± 1.16
Reference	12.22 ± 1.32	67.76 ± 0.71	1.63 ± 0.14	18.88 ± 0.83	8.60 ± 0.41	32.24 ± 0.71
P Value	0.9047	0.5619	0.1864	0.9603	0.6917	0.5619

Table 3.

Apparent digestibility values of the reference and experimental diets (means ± S.E.)						
Diet	Organic matter	Dry matter	Protein	Energy	Lipid	Lysine
Empyreal 75-1	86.40 ± 0.28	76.79 ± 0.62	91.35 ± 0.35	86.25 ± 0.37	94.98 ± 1.31	96.33 ± 0.11
Empyreal 75-2	86.59 ± 0.88	76.26 ± 1.82	91.15 ± 0.42	86.98 ± 0.87	95.96 ± 0.30	96.37 ± 0.29
Lysto	87.12 ± 0.77	78.26 ± 1.34	91.45 ± 0.65	87.60 ± 0.55	96.18 ± 0.57	96.99 ± 0.36
Corn Gluten	86.58 ± 0.67	76.15 ± 1.48	90.74 ± 0.74	86.89 ± 0.82	95.25 ± 1.33	96.96 ± 0.21
Reference	86.95 ± 0.69	77.29 ± 0.74	91.70 ± 0.56	87.71 ± 0.83	94.97 ± 0.31	97.16 ± 0.12
P Value	0.9394	0.7794	0.8225	0.5816	0.7890	0.1133

Table 4.

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