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Comparing the effects of feeding a grain- or a fish meal-based diet on water quality, waste production, and rainbow trout *Oncorhynchus mykiss* performance within low exchange water recirculating aquaculture systems

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ABSTRACT

Feeding a fish meal-free grain-based diet (GB) was compared to feeding a fish meal-based diet (FM) relative to water quality criteria, waste production, water treatment process performance, and rainbow trout *Oncorhynchus mykiss* performance within six replicated water recirculating aquaculture systems (WRAS) operated at low exchange (0.26% of the total recycle flow; system hydraulic retention time = 6.7 days). Rainbow trout (214 ± 3 g to begin) were fed the GB diet within three WRAS and the FM diet within the other three WRAS for 3 months. Feeding the GB diet resulted in significantly greater total ammonia nitrogen (TAN) throughout the study, as well as significantly greater total suspended solids (TSS) and carbonaceous biochemical oxygen demand (BOD) over the greater part of the study. Greater counts of fine solids (2–30 μm) were associated with the GB diet. Water clarity was improved for the GB diet as reflected by significantly reduced true color and increased ultraviolet transmittance. Total and dissolved phosphorous, as well as the daily mass captured per kg feed of total phosphorous were significantly lower within the effluent associated with the GB diet. The daily mass of total nitrogen and TSS captured per kg feed and discharged from each WRAS was equal between diets, but waste load among three discharge flows varied. Waste removal efficiency across unit processes was similar between diets, with the exception of solids removal efficiency across the microscreen drum filter and the radial flow settler, which was generally lower for the GB diet. Rainbow trout growth, feed conversion, condition factor, and survival were similar between diets. Survival was 99.5 ± 0.2% for both diet treatments. Skin-on fillet yield and whole-body protein levels were significantly greater at the end of the study for trout fed the GB diet. Overall, the GB diet evaluated during the present study proved to be a viable feed option for use within a low exchange WRAS. However, further refinements to grain-based diet formulations and/or use of ozone to improve water quality when feeding GB diets within low exchange WRAS could be beneficial.

1. Introduction

The majority of the world's food fish supply (including finfish, crustaceans, and mollusks) has historically been provided by capture fisheries; however, a recent report issued by the Food and Agriculture Organization of the United Nations (FAO) indicated that aquaculture provided nearly half of the world's fish in 2008 and will produce more than half of global food fish by 2012 (FAO, 2010). If aquaculture is to continue to grow and supply much of the world's food fish, the industry will need to identify alternatives to traditional fish meal and fish oil feed ingredients that are economical, environmentally friendly, and sustainable (Gatlin et al., 2007). The relatively static or possibly diminishing supply of fish meal most likely will not meet the demand for protein that will accompany the projected increase in worldwide aquaculture production (Naylor et al., 2000; Gatlin et al., 2007; FAO, 2008; Tacon and Metian, 2008; Naylor et al., 2009). In addition, the market price for fish meal and fish oil has continued to rise due to increased demand, as well as increasing energy costs related to fishing, processing, and transportation (Tacon and Metian, 2008), which has driven the aquafeeds industry to consider more economical protein sources.

The aquaculture research community and the aquafeeds industry have long recognized and anticipated issues impacting the

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sustainability of fish meal in aquafeeds (Barrows and Hardy, 2001) and have been researching and developing aquafeeds that use alternative protein ingredients, particularly plant-derived proteins (Gatlin et al., 2007). Significant progress has been made towards the development of aquafeeds containing plant-based proteins. Recent literature indicates that growth performance of rainbow trout fed all-plant-protein diets without fish meal is comparable to that of trout fed traditional fish meal diets (Kaushik et al., 1995; Gaylord et al., 2007; Barrows et al., 2007). In addition, important information has been gleaned from studies evaluating feed palatability (Stickney et al., 1996), nutritional content (Apines et al., 2003), digestibility (Storebakken et al., 1998; Drew et al., 2005; Gaylord et al., 2008), anti-nutrients (Francis et al., 2001), and flesh quality (Bjerkeng et al., 1997; Brinker and Reiter, 2011) resulting in substantial improvements in grain-based diets for salmonids.

Although significant advancements have been made relative to nutritional and performance metrics for grain-based diets, very little information is available regarding the effects of grain-based diets on water quality, waste production, water treatment process performance, or fish performance when these diets are fed within water recirculating aquaculture systems (WRAS). Water recirculating aquaculture systems offer many advantages for fish culture (Summerfelt and Vinci, 2008) and are considered by many to be an environmentally friendly and sustainable technology; thus use of WRAS by the aquaculture industry has increased in recent years (Summerfelt and Vinci, 2008). Therefore, alternative protein aquafeeds fed within WRAS, including those containing plant-based proteins, must be compatible relative to fish and system performance.

The primary objectives of the present study were to compare the effects of feeding a grain-based diet and a fish meal-based diet on water quality, rainbow trout performance, product quality, unit process removal efficiencies, and waste production within replicated recirculating aquaculture systems operated at low water exchange rates.

2. Methods

2.1. Experimental treatments and system flushing

Six replicated WRAS (9.5 m^3) were used (Fig. 1); fish in three systems were fed a grain-based (GB) diet and fish in the remaining three systems were fed a fish meal-based (FM) diet. The study was conducted for 3 months. The experimental diets were manufactured by Zeigler Brothers, Inc. (Gardners, PA, USA) using commercial facilities and manufacturing methods. The diets were formulated to contain equal levels of digestible protein using apparent digestibility coefficients reported by Gaylord et al. (2008). The primary protein ingredients in the GB diet were soy and corn protein concentrates (Table 1). The FM diet was formulated to represent a typical trout diet containing menhaden meal, poultry byproduct, soybean meal, and blood meal (Table 1). Fish oil was included in both diets, as well as astaxanthin pigment (30 ppm). Proximate analysis conducted on each diet provided the following information: moisture (%), wet and dry protein and fat (%), and wet and dry measurements of energy content (Table 2).

2.2. System description

The WRAS used during the present study (Fig. 1) were described in detail in Davidson et al. (2009). To summarize, each system recirculated 380 L/min (100 gpm) of water through a 5.3 m^3 dual drain culture tank, a radial flow settler, a microscreen drum filter with 60 μm screens, a fluidized sand biofilter, a geothermal heat exchanger, a carbon dioxide stripping column, and a low head oxygenator (LHO) (Fig. 1). The recirculating flow exchanged the culture tank water volume once every 15 min. Approximately 1 L/min of makeup water was continuously added to each pump sump, which was equivalent to 0.26% of the total recycle flow and a mean system hydraulic retention time of approximately 6.7 days. Mean feed loading rates were maintained at 3.30 kg feed/m^3 daily makeup water for each WRAS and maximum feed loading rates reached 5.14 kg feed/m^3 daily makeup water. Sodium bicarbonate ($NaHCO_3$) was added to each WRAS as needed to maintain alkalinity at approximately 200 mg/L.

2.3. Rainbow trout

Rainbow trout (214 ± 3 g) were stocked at a density of approximately 57 kg/m^3 (1400 fish/tank) to begin. Fish were reared to a maximum density of 100 kg/m^3 and were culled 8 weeks into the study to reduce fish density to approximately 25 kg/m^3.

Table 1
Ingredient and nutrient composition of experimental diets.

Ingredient	Fish meal (g/kg (as-fed))	Plant meal (g/kg (as-fed))
Soy protein concentrate[a]	–	246.4
Corn protein concentrate[b]	55.3	175.4
Fish meal[c]	215.5	–
Soybean meal[d]	158.4	133.0
Wheat flour[e]	191.8	164.8
Blood meal[f]	59.0	–
Poultry meal[g]	138.0	–
Menahaden oil[h]	162.0	195.9
Vitamin premix[i]	10.0	10.0
Lysine		19.9
Methionine		5.0
Taurine		5.0
Dicalcium phosphate	–	26.5
Trace min. premix[j]	1.0	1.0
Choline CL	6.0	6.0
Stay-C	2.0	2.0
Potassium chloride	–	5.6
Magnesium oxide	–	0.6
Sodium chloride	–	2.8
Astazanthin[k]	0.1	0.1

[a] Solae, Pro-Fine VF, 693 g/kg crude protein.
[b] Cargill, Empyreal 75, 761.0 g/kg protein.
[c] Omega Proteins, Menhanden Special Select, 628 g/kg protein.
[d] ADM Inc., 480 g/kg protein.
[e] Manildra Milling, 120 g/kg protein.
[f] IDF Inc., 832 g/kg protein.
[g] American Dehydrated Foods, 734 g/kg protein.
[h] Omega Proteins Inc.
[i] ARS 702; contributed, per kg diet; vitamin A 9650 IU; vitamin D 6600 IU; vitamin E 132 IU; vitamin K3 1.1 g: thiamin mononitrate 9.1 mg; riboflavin 9.6 mg; pyridoxine hydrochloride 13.7 mg; pantothenate DL-calcium 46.5; cyancobalamin 0.03 mg; nicotinic acid 21.8 mg; biotin 0.34 mg; folic acid 2.5; inostitol 600.
[j] DSM Nutritional Products.
[k] Contributed in mg/kg of diet; zinc 40; manganese 13; iodine 5; copper 9.

Table 2
Proximate analysis results of the grain-based and fish meal-based diets used during the present study.

	GB diet	FM diet
Moisture (%)	5.1	7.4
Fat (%) – wet	16.8	19.0
Protein (%) – wet	44.9	41.1
Energy (kJ/g) – wet	22.57	21.58
Fat (%) – dry	17.7	20.5
Protein (%) – dry	47.3	44.3
Energy (%) – dry	5680	5565