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Evaluation of distiller's dried grains with solubles (DDGS) and high protein distiller's dried grains (HPDDG) in diets for rainbow trout (*Oncorhynchus mykiss*)

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ABSTRACT

Two different sources of maize distiller's co-products, distiller's dried grains with solubles (DDGS) and high protein distiller's dried grains (HPDDG), were evaluated as dietary ingredients in growth experiments (77 days) with rainbow trout (*Oncorhynchus mykiss*). In Exp. 1, the dietary treatments consisted of a control diet based on fish meal, sunflower meal, rapeseed meal, and field peas, and two diets with 250 or 500 g kg^{-1} DDGS, substituting 50 (DDGS50 diet) or 100% (DDGS100 diet) of the plant protein ingredients, respectively. In Exp. 2, the dietary treatments were a control diet based on fish meal, soy protein concentrate, sunflower meal and rapeseed meal, and two diets with 225 or 450 g kg^{-1} HPDDG, substituting 50 (HPDDG50 diet) or 100% (HPDDG100 diet) of the plant protein sources, respectively. Each experiment was conducted using 9 triplicate fresh water tanks of 20 rainbow trout with an initial weight of 143 g. In Exp. 1, feeding the DDGS50 diet resulted in higher feed intake and weight gain and lower feed conversion ratio (FCR) than in trout fed the control diet, while feeding the DDGS100 diet resulted in a lower FCR compared with the control and the DDGS50 diets. Adding DDGS to diets did not affect the digestibility of protein, most amino acids, or phosphorus, but the DDGS-containing diets tended ($P < 0.07$) to increase energy digestibility. Fish fed the DDGS100 diet had higher ($P < 0.01$) energy and phosphorus retention than those fed the control diet, and had higher ($P < 0.01$) nitrogen retention than those fed the control and DDGS50 diets. In Exp. 2, there was no difference in feed intake, weight gain or FCR of fish fed the control or the HPDDG diets. Rainbow trout fed the HPDDG100 and HPDDG50 diets had higher ($P < 0.05$) energy digestibility compared with those fed the control diet. Feeding the HPDDG100 diet resulted in lower ($P < 0.01$) protein digestibility, but higher ($P < 0.01$) phosphorus digestibility and retention than those fed the control and the HPDDG50 diets. The HPDDG100 diet resulted in lower ($P < 0.05$) digestibility of most amino acids compared with the control diet, except for cysteine digestibility that was significantly higher ($P < 0.05$), but neither of the HPDDG diets affected retention of energy or nitrogen of the fish. Neither the DDGS nor the HPDDG diets affected the relative weight of the distal intestine, intestinal enzyme activity, or plasma metabolites. To conclude, both DGGS and HPDDG were shown to be suitable energy, protein, and phosphorus sources up to the level tested when substituting typical plant ingredients in diets for rainbow trout.

1. Introduction

The extensive growth of the U.S. ethanol industry has led to the production of large quantities (34.4 million metric tons in 2012) of maize co-products from dry-grind ethanol production (Renewable Fuels Association, 2013). Dried distiller's grains with solubles (DDGS) is the predominant maize co-product produced by dry-grind fuel ethanol plants, consisting of distiller's grains combined with the condensed solubles obtained after yeast fermentation to produce ethanol, and typically contain about 27% crude protein (CP), 7% starch, 42% neutral detergent fiber, and 0.6% phosphorus (Stein and Shurson, 2009).

Historically, the majority of distiller's co-products produced in the U.S.A. have been used in ruminant feeds, but because DDGS is high in digestible energy, protein, and phosphorus content, it has also become an economical and widely used ingredient in swine and poultry diets (Stein and Shurson, 2009). At present, less than 1% of the total DDGS produced is being used in aquaculture feeds (Shurson, 2012). The rapid growth in the aquaculture industry (FAO, 2012) has caused increased demands on global feed resources. The limited supply and record high prices of fish meal have created an incentive to use less expensive and abundant alternative energy and protein sources, such as DDGS, in aquaculture feeds. The use of DDGS in diets for salmonids

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has, however, given inconsistent results. Cheng and Hardy (2004) showed that DDGS could be used at 150 g kg^{-1} in rainbow trout diets to replace 50% of the fish meal on an isonitrogenous and isoenergetic basis without affecting growth and feed conversion. When the diets were supplemented with lysine and methionine, up to 225 g kg^{-1} DDGS can be added to replace up to 75% of fish meal in the rainbow trout diets without negative effects on weight gain and feed conversion. However, Barnes et al. (2012a) reported reduced gain in hatchery reared juvenile rainbow trout when fed diets containing 100 or 200 g kg^{-1} DDGS, even when supplemented with essential amino acids and phytase.

Distiller's grain co-products may be more attractive for use in aquaculture feeds if the protein level was increased and the indigestible fiber content was reduced (Stone et al., 2005). This can be achieved by use of front-end fractionation technology to separate the fermentable portion of the corn kernel from the non-fermentable portion prior to grinding and further processing by yeast fermentation in dry-grind ethanol plants (Robinson et al., 2008; Singh et al., 2005). One of the resulting co-products produced by this process is a high protein dried distiller's grains (HPDDG) which is higher in crude protein, and lower in fat and fiber than conventional DDGS (Singh et al., 2005). Studies by Barnes et al. (2012b) indicated that at least 200 g kg^{-1} HPDDG, if supplemented with amino acids, may be used to replace fish meal in diets for juvenile rainbow trout. However, Barnes et al. (2012c) concluded that replacement of fish meal with HPDDG in diets for juvenile rainbow trout may only be suitable at levels of less than 100 g kg^{-1}.

Due to the use of maize as a feedstock in ethanol production, and the fermentation and hydrothermal treatment processes inherent in the process, the presence of typical antinutritional factors (ANF) such as phytic acid is lower than in most plant ingredients. Because yeast from *Saccharomyces cerevisiae* is used in the fermentation step, DDGS products are partially made up from yeast remnants. According to Ingledew (1999) the contribution of yeast biomass to the weight of DDGS is at least 3.9%, and the proportion of yeast protein in the total protein content of DDGS could be at least 5.3%. *S. cerevisiae* has recently been evaluated as a potential protein source in aquaculture feeds (Øverland et al., 2013), and yeast cells are sources of nucleic acids, mannan oligosaccharides, and β-glucans that can be used as immunostimulants in fish diets (Li and Gatlin III, 2006; Refstie et al., 2010).

DDGS has been reported to be a suitable feed ingredient to replace plant protein sources in diets for fish species such as tilapia (Coyle et al., 2004; Shelby et al., 2008) and channel catfish (Li et al., 2010, 2011). In previous studies with salmonids, however, DDGS and HPDDG have been used mainly as substitutes for fish meal protein. The recent development towards the reduced supply and high cost of fish meal has led to increased use of plant protein sources in diets for salmonids and the need to evaluate distiller's grain co-products as promising alternatives to commonly used plant protein ingredients, such as soy protein concentrate. Therefore, the aim of the present study was to assess growth performance, digestibility and retention of energy and nutrients, liver and distal intestine weights, blood chemistry, and gut enzyme activity of rainbow trout fed diets containing conventional DDGS or HPDDG produced from maize-based ethanol production.

2. Materials and methods

Two growth performance experiments, Exp. 1 and Exp. 2, evaluated two different sources of distiller's grains co-products, DDGS and HPDDG, in diets for rainbow trout at the fish laboratory of the Norwegian University of Life Sciences, Ås, Norway.

2.1. Diets

In Exp. 1, the dietary treatments were: 1) a control diet (35% CP) based on fish meal, sunflower expeller meal, rapeseed meal, and field peas, 2) a test diet containing 250 g kg^{-1} DDGS, and 3) a test diet containing 500 g kg^{-1} DDGS. The DDGS partly (DDGS50 diet) or fully (DDGS100 diet) replaced a mixture of the plant protein ingredients used in the control diet. In Exp. 2, the dietary treatments were: 1) a control diet (43% CP) based on fish meal, soy protein concentrate, sunflower expeller meal, and rapeseed meal, 2) a test diet containing 225 g kg^{-1} HPDDG, and 3) a test diet containing 450 g kg^{-1} HPDDG. The HPDDG partly (HPDDG50 diet) or fully (HPDDG100 diet) replaced a mixture of the plant protein ingredients. Samples of the DDGS and HPDDG sources used in these experiments were analyzed for chemical composition and mycotoxin concentrations. In both experiments, diets were formulated to have a similar level of crude protein and gross energy based on the analyzed chemical content of the ingredients. All diets contained 0.1 g kg^{-1} yttrium oxide (Y_2O_3) as an indigestible marker for determination of nutrient digestibility (Austreng et al., 2000). The chemical composition of ingredients is shown in Table 1, while the ingredient composition and chemical analysis of the experimental diets used in Exp. 1 and 2 are shown in Table 2.

The diets in Exp.1 and 2 were processed at the feed laboratory of the Norwegian University of Life Sciences, Ås, Norway. Gelatin and pre-gelatinzed potato starch were used as pellet binders. Except gelatin, the dry ingredients and the fish oil were mixed in a Moretti Foreni kneading machine (Spiry 25, Mondolfo, Italy). Gelatin was dissolved in hot water (50–60 °C) and applied to the rest of the ingredients during mixing. The moist (70–75% DM) dough was subsequently cold pelleted in an Italgi pasta extruder (P35A, Carasco, Italy) equipped with a 3 mm die. The semi-moist pellets were gently dried on large perforated trays in an oven at 55–60 °C to obtain a final DM content of about 90–95%. The diets were stored at −18 °C until feeding.

2.2. Fish husbandry and sampling

In both Exp. 1 and 2, a total of 180 rainbow trout (*Oncorhynchus mykiss*) with an average initial weight of 143 g were randomly

Table 1
Chemical composition of ingredients in Exp. 1 and Exp. 2.

Analyzed composition, g kg^{-1}	FM[1]	SPC[2]	SFM[3]	RSM[4]	Peas[5]	DDGS[6]	HPDDG[6]
Dry matter	911	912	898	903	882	956	957
Crude protein	677	626	342	301	210	275	447
Amino acids, g 16 g N^{-1}[7]							
Essential amino acids							
Arginine	5.2	6.9	7.1	5.7	7.4	5.0	4.4
Histidine	2.0	2.8	2.6	2.8	2.5	3.0	2.8
Isoleucine	3.4	4.5	3.9	3.9	4.1	3.7	4.1
Leucine	6.3	7.0	6.2	6.3	6.5	10.5	9.6
Lysine	6.8	6.1	3.7	5.5	7.0	2.9	4.7
Methionine	2.5	1.3	2.1	1.9	0.9	1.8	2.0
Phenylalanine	3.3	4.7	4.3	3.7	4.5	4.6	4.5
Threonine	4.0	3.7	3.5	4.2	3.5	3.7	4.1
Valine	3.9	4.7	4.7	5.1	4.6	5.1	5.3
Non-essential amino acids							
Alanine	5.0	3.6	3.8	3.7	3.6	6.5	5.7
Aspartic acid	8.2	10.4	8.2	6.9	10.2	6.4	7.3
Cysteine	0.8	1.4	1.5	2.2	1.4	1.9	1.7
Glycine	4.4	3.1	4.1	3.8	3.2	3.4	3.2
Glutamic acid	11.9	16.8	17.5	15.2	15.1	16.6	14.1
Proline	3.3	4.3	3.8	5.0	3.5	7.0	6.0
Serine	4.0	4.7	3.9	4.0	4.3	4.7	4.7
Tyrosine	2.6	3.1	2.5	2.7	2.7	3.2	3.5
Crude fat	114	4	20	103	18	185	54
Starch	10	24.8	85.1	39.1	403	53	62
Neutral detergent fiber	–	64	230	245	103	265	73
Ash	139	63	61	59	25	36	36

[1] NorsECO-LT, Egersund Sildoljefabrikk AS, Egersund, Norway.
[2] Soycomil® R, ADM Specialty Ingredients Europe, Koog aan de Zaan, Holland.
[3] Defatted, 35% crude protein.
[4] Solvent extracted (hexane) double low rapeseed meal, ExPro-00E (Karlshamn AB, Karlshamn, Sweden).
[5] Eldorado, Norway.
[6] Steve Markham at Cenex Harvest States, Inc., Inver Grove Heights, MN, USA.
[7] Water corrected amino acids.