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Travis W. Schaeffer
*South Dakota State University*

Michael L. Brown
*South Dakota State University*

Kurt A. Rosentrater
*USDA, Agricultural Research Service*

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ARTICLE

# Effects of Dietary Distillers Dried Grains with Solubles and Soybean Meal on Extruded Pellet Characteristics and Growth Responses of Juvenile Yellow Perch

**Travis W. Schaeffer[1] and Michael L. Brown***
*Department of Wildlife and Fisheries Sciences, South Dakota State University, Box 2140B, Northern Plains Biostress Laboratory, Brookings, South Dakota 57007, USA*

**Kurt A. Rosentrater**
*U.S. Department of Agriculture, Agricultural Research Service, North-Central Agricultural Research Laboratory, 2923 Medary Avenue, Brookings, South Dakota 57006, USA*

***Abstract***

**A 126-d feeding trial was performed to investigate graded combinations of distillers dried grains with solubles (DDGS) and soybean meal (SBM) in diets formulated for yellow perch *Perca flavescens*. Six experimental diets contained DDGS and SBM at 0 and 31.5% (dry matter basis), respectively (0/31.5 diet), 10 and 26% (10/26), 20 and 20.5% (20/20.5), 30 and 15% (30/15), 40 and 9.5% (40/9.5), and 50 and 4% (50/4) to obtain similar levels of crude protein (mean ± SE = 30.1 ± 0.2%), crude lipid (16.7 ± 0.7%), and digestible energy (13.5 ± 0.2 kJ/g). Fourteen fish (initial individual weight = 19.1 ± 0.5 g) were randomly selected and stocked into each of twenty-four 110-L tanks (4 replicate tanks/diet). Common biological and mechanical filter systems were used to recirculate the water and maintain similar water quality. Fish that received the 40/9.5 diet exhibited the highest apparent absolute weight gain and percent weight gain, while fish that were fed the 10/26, 20/20.5, 30/15, and 40/9.5 diets exhibited similar absolute weight gain. Fish that were given the 20/20.5, 30/15, and 40/9.5 diets also exhibited similar percent weight gain. Fulton's condition factor and apparent protein digestibility were significantly lower and higher, respectively, for fish that received the 50/4 diet than for all other treatment groups. Crude protein and crude lipid levels in muscle samples did not significantly differ among treatment groups. Results indicated that yellow perch can utilize DDGS plus SBM at a combined inclusion level of up to 49.5% without negative effects on growth. The mechanical strength and color of the extruded pellets were related to the level of DDGS plus SBM in the feed blends. Hepatosomatic indices were correlated with pellet color, while protein digestibility decreased with increasing pellet strength.**

In response to collapsed commercial fisheries in the Great Lakes and increased demand in other regions, culture of yellow perch *Perca flavescens* has been increasing in the United States, primarily in the north-central region, where a niche market has been established (Kasper et al. 2007). The 2005 Census of Aquaculture indicated that there were 121 aquaculture producers of yellow perch (USDA 2010b) in 2005, whereas only 86 producers were reported in 1998 (USDA 2010a). Aquaculture production levels of yellow perch are not well known but are thought to be less than 2.3 million kg annually (Brown and Barrows 2002). Yellow perch can be cultured in earthen ponds, raceways, cages, and tank systems (Brown and Barrows 2002); however, most interest has focused on intensive culture in ponds, raceways, and indoor tank systems (Kasper et al. 2007). Such intensive culture practices require efficient formulated diets that promote high growth performance while minimizing waste.

*Corresponding author: Michael.Brown@sdstate.edu
[1]Present address: U.S. Geological Survey, Yankton Field Research Station, 31247 436th Avenue, Yankton, South Dakota 57078, USA.
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TABLE 1. Quantitative nutritional requirements (dry matter basis) of yellow perch and Eurasian perch (N/A = not applicable).

| Species | Fish size (g) | Nutrient | Requirement | Diet type[a] | References |
|---|---|---|---|---|---|
| Yellow perch | 2.1 | Protein/GE[b] | 24.4–26.2 g/MJ | Practical | Reinitz and Austin 1980 |
| | 2.1 | Protein/ME[b] | 32.9–36.4 g/MJ | Practical | Reinitz and Austin 1980 |
| | 18.6–27.1 | Protein/ME[b] | 22 g/MJ | Semipurified | Ramseyer and Garling 1998 |
| | 18.6–27.1 | Protein | 21–27% | Semipurified | Ramseyer and Garling 1998 |
| | 25.0 | Lipid | 6% | Purified | Cartwright 1998 |
| | 16.0 | Choline | 598–634 mg/kg | Purified | Twibell and Brown 2000 |
| Eurasian perch | 2.9 | Protein/GE[b] | 18.4–21.8 g/MJ | Semipurified | Fiogbé et al. 1996 |
| | 2.9 | Protein | 36.8–43.6% | Semipurified | Fiogbé et al. 1996 |
| | 22.7 | Lipid[c] | 12–18% | Practical | Kestemont et al. 2001 |
| | 33.1–35.9 | Lipid | 19.3% | N/A | Xu et al. 2001 |

[a]Diet type is based on purified ingredients used (practical = no purified ingredients; semipurified = some purified ingredients; purified = all purified ingredients).
[b]Expressed as grams of protein per megajoule of metabolizable energy (ME) or gross energy (GE).
[c]Ethoxyquin was added to lipid sources.

Relatively few studies have discussed the nutritional requirements of the yellow perch or its European counterpart, the Eurasian perch *P. fluviatilis*; published nutritional requirements for both species are summarized in Table 1. Because of the lack of information on yellow perch nutritional requirements, recommended diets for commercial yellow perch culture are often formulated to meet the dietary requirements of salmonids (Brown et al. 1996). In general, salmonid diets contain high levels of fish meal (FM) and fish lipid as primary nutrient and energy sources. Fish meal provides an important source of protein because of its well-balanced profile of amino acids, essential fatty acids, digestible energy, vitamins, and minerals (Abdelghany 2003); however, researchers have examined numerous alternative protein sources because of the rising costs, uncertain availability, and environmental impacts associated with obtaining and using FM (Jauncey and Ross 1982; Fontaínhas-Fernandes et al. 1999; Coyle et al. 2004). Some of these alternatives include fishery byproducts (e.g., fish waste, fish silage, etc.), rendering byproducts (e.g., meat and bone meal, blood meal, poultry byproduct meal, and feather meal), and plant-based feeds (e.g., corn gluten meal, corn gluten feed, cottonseed meal, alfalfa meal, canola meal, field peas, and various bean products; Hertrampf and Piedad-Pascual 2000). One protein source that is increasingly available for aquaculture feeds is distillers dried grains with solubles (DDGS).

Distillers dried grains with solubles is predominantly produced as a coproduct of dry-grind fuel ethanol processing and, to a lesser extent, the manufacture of beverage alcohols (i.e., distilleries; Rosentrater and Muthukumarappan 2006). In early 2010, 201 operating ethanol plants produced a total of $51 \times 10^9$ L of ethanol, and the estimated industry expansion was nearly $4.9 \times 10^9$ L (RFA 2010). Given the exponential growth in fuel ethanol production in recent years, significant quantities of distillers grains are now produced. Compared with raw corn, corn meal, and other corn flour products, DDGS often contains up to three times the normal concentration of nutrients; this is attributable to starch consumption by yeast metabolism during fermentation (Chevanan et al. 2005, 2008). The DDGS coproduct typically contains 26.8–33.7% protein (Rosentrater and Muthukumarappan 2006). Also, DDGS does not contain the antinutritional factors (e.g., trypsin inhibitors, lectins, tannins, oligosaccharides, saponins, and gossypol) that can be present in soybean meal (SBM; Wilson and Poe 1985; Shiau et al. 1987) and cottonseed meal (Jauncey and Ross 1982; Robinson 1991). Several studies have indicated positive performance of omnivorous fish that were fed diets containing varying levels of DDGS (Webster et al. 1992a, 1992b, 1993; Wu et al. 1996, 1997; Coyle et al. 2004; Lim et al. 2007).

Another plant-based protein often used in aquaculture diets is SBM. Because of its high protein content, amino acid profile, and global availability, SBM is currently one of the most important and highly used protein sources for partial or entire replacement of FM in aquaculture diets (Hertrampf and Piedad-Pascual 2000). Defatted SBM is also a coproduct material and is generated by the extraction of oil from soybeans *Glycine max* (Hertrampf and Piedad-Pascual 2000). Unlike DDGS, SBM contains several antinutritional compounds; however, its relatively well-balanced nutritional composition, especially protein content and amino acid profile, allows for the use of SBM as a constituent in aquaculture diets (Hertrampf and Piedad-Pascual 2000).

Due to the high availability, low cost, and nutrient composition of DDGS and SBM, these coproducts may be used as relatively inexpensive protein supplements to provide low-cost diet formulations. To our knowledge, only one study (Kasper et al. 2007) has evaluated the use of alternative protein sources (i.e., SBM) in diets for yellow perch, and no studies have explored the use of DDGS in yellow perch diets. Likewise, only a few studies have examined processing conditions for the production of pelleted aquaculture feeds based on DDGS and SBM (Chevanan et al. 2007; Kannadhason et al. 2010), and no studies have simultaneously examined feed processing aspects of DDGS and the culture performance of yellow perch. Thus, the objectives of the present study were to (1) evaluate the growth

TABLE 2. Ingredient composition (%, dry matter basis), digestible energy (DE), and crude protein (CP) per megajoule of DE (CP/DE) for experimental diets containing distillers dried grains with solubles (DDGS) and soybean meal (SBM).

| | Diet | | | | | |
|---|---|---|---|---|---|---|
| Ingredient or component | 1 | 2 | 3 | 4 | 5 | 6 |
| Ingredients | | | | | | |
| DDGS[a] | 0 | 10 | 20 | 30 | 40 | 50 |
| SBM[b] | 31.5 | 26 | 20.5 | 15 | 9.5 | 4 |
| Celufil[c] | 17 | 13.6 | 10.2 | 6.8 | 3.4 | 0 |
| Menhaden fish meal[d] | 24 | 24 | 24 | 24 | 24 | 24 |
| CMC[e] | 5 | 5 | 5 | 5 | 5 | 5 |
| Menhaden oil[f] | 6 | 6 | 6 | 6 | 6 | 6 |
| Soybean oil[g] | 5.5 | 4.4 | 3.3 | 2.2 | 1.1 | 0 |
| Vitamin mix[h] | 3 | 3 | 3 | 3 | 3 | 3 |
| Mineral mix[i] | 8 | 8 | 8 | 8 | 8 | 8 |
| Proximate composition | | | | | | |
| CP (%) | 29.5 | 29.6 | 30.4 | 30.4 | 30.2 | 30.3 |
| Crude lipid (%) | 16.0 | 16.6 | 16.4 | 16.4 | 16.7 | 18.1 |
| DE (kJ/g) | 13.8 | 13.6 | 13.5 | 13.4 | 13.3 | 13.2 |
| CP/DE (g/MJ) | 21.4 | 21.7 | 22.5 | 22.7 | 22.7 | 23.0 |

[a]Dakota Ethanol, Wentworth, South Dakota.
[b]Dakota Land Feeds, Huron, South Dakota.
[c]U.S. Biochemical Corp., Cleveland, Ohio.
[d]IPC 740; International Proteins Corp., Minneapolis, Minnesota.
[e]Akucell AF 2785 carboxymethylcellulose (CMC); Akzo Nobel Functional Chemicals, Amsterdam, The Netherlands.
[f]Virginia Prime; Omega Protein, Inc., Reedville, Virginia.
[g]Product number OF1870E; Consumers Supply Distributing, Sioux City, Iowa.
[h]TestDiet, Land O'Lakes Purina Feed, Richmond, Indiana. Pantothenic acid, 4,601 mg/kg; pyridoxine, 823 mg/kg; riboflavin, 3,000 mg/kg; niacin, 5,000 mg/kg; folic acid, 1,800 mg/kg; thiamin hydrochloride, 4,503 mg/kg; biotin, 500 mg/kg; vitamin $B_{12}$, 200 μg/kg; choline, 50,001 mg/kg, menadione, 1,040 mg/kg; vitamin A, 96.1 international units (IU)/g; vitamin $D_3$, 120 IU/g; vitamin E, 3,000 IU/kg; and ascorbic acid (L-ascorbyl-2-polyphosphate), 17,500 mg/kg.
[i]TestDiet, Land O'Lakes Purina Feed. Calcium, 8.00%; phosphorus, 8.00%; potassium, 5.00%; magnesium, 1.33%; sodium, 3.48%; chloride, 2.80%; fluorine, 144 mg/kg; iron, 1,600 mg/kg; zinc, 1,091 mg/kg; manganese, 276 mg/kg; copper, 126.2 mg/kg; cobalt, 248.1 mg/kg; iodine, 114.68 mg/kg; chromium, 8.0 mg/kg; molybdenum, 5.61 mg/kg; and selenium, 5.02 mg/kg.

performance and resulting condition and muscle composition of yellow perch that received semipurified diets containing various proportions of fuel-based DDGS and SBM and (2) examine potential relationships between feed pellet characteristics and yellow perch growth performance.

## METHODS

*Experimental diets and fish.*—Six semipurified diets were formulated with fuel-based DDGS and solvent-extracted SBM at various levels to determine which combination produced the best growth and use responses. The diets (24% FM) contained DDGS and SBM at 0 and 31.5% (dry matter basis), respectively (0/31.5 diet), 10 and 26% (10/26), 20 and 20.5% (20/20.5), 30 and 15% (30/15), 40 and 9.5% (40/9.5), and 50 and 4% (50/4). These diets were formulated to contain similar levels of crude protein (CP; mean ± SE = 30.1 ± 0.2%), crude lipid (16.7 ± 0.7%), and digestible energy (13.5 ± 0.2 kJ/g; Table 2) so as to meet the published nutritional requirements of yellow perch or Eurasian perch (Table 1). Fuel-based DDGS was obtained from the Dakota Ethanol Plant, while SBM was obtained from Dakota Land Feeds. Prior to use in the experimental diets, both ingredients were analyzed for proximate composition by Servi-Tech Laboratories (Hastings, Nebraska; Table 3). Because of the limited information on quantitative dietary requirements of yellow perch, vitamin and mineral premixes were formulated to meet the nutritional requirements of rainbow trout *Oncorhynchus mykiss* (NRC 1993) and were obtained from TestDiet (Land O'Lakes Purina Feed).

As described by Ayadi et al. (2009) and Chevanan et al. (2009), diets were extruded by use of a single screw extruder

TABLE 3. Composition (%, dry matter basis) of distillers dried grains with solubles (DDGS) and soybean meal (SBM) used in yellow perch diets. Dry matter content of DDGS and SBM used in this study was 95.3% and 88.7%, respectively.

| Component | DDGS | SBM |
|---|---|---|
| Crude protein | 27.9 | 51.0 |
| Crude lipid | 11.5 | 0.8 |
| Ash | 4.0 | 7.0 |
| Carbohydrate | | |
| Crude fiber | 6.6 | 4.2 |
| Nitrogen-free extract | 50.0 | 37.0 |

TABLE 4. Amino acids (%, dry matter basis) in experimental diets containing various levels of distillers dried grains with solubles (DDGS) and soybean meal (SBM); estimated requirements for yellow perch (from Hart et al. 2010) are also presented.

| | DDGS (%)/SBM (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| Amino acid | 0/31.5 | 10/26 | 20/20.5 | 30/15 | 40/9.5 | 50/4 | Estimated requirement |
| Arginine | 2.00 | 2.00 | 1.89 | 1.98 | 1.89 | 1.73 | 2.0 |
| Histidine | 0.65 | 0.68 | 0.66 | 0.73 | 0.71 | 0.68 | 0.9 |
| Isoleucine | 1.16 | 1.13 | 1.15 | 1.20 | 1.14 | 1.14 | 1.4 |
| Leucine | 2.04 | 2.14 | 2.29 | 2.48 | 2.62 | 2.70 | 2.3 |
| Lysine | 1.71 | 1.67 | 1.64 | 1.61 | 1.48 | 1.44 | 2.6 |
| Methionine + cystine | 1.29 | 1.42 | 1.39 | 1.43 | 2.03 | 1.67 | 0.8 |
| Phenylalanine | 1.28 | 1.31 | 1.27 | 1.37 | 1.35 | 1.25 | 1.4 |
| Threonine | 1.16 | 1.28 | 1.18 | 1.26 | 1.27 | 1.20 | 1.4 |
| Tryptophan[a] | 0.32 | 0.33 | 0.31 | 0.28 | 0.26 | 0.23 | 0.3 |
| Valine | 1.26 | 1.25 | 1.31 | 1.40 | 1.36 | 1.39 | 1.6 |

[a]Percentages estimated based on ingredient values from the National Research Council (NRC 1993).

(19.05-mm [0.75-in] barrel diameter; Plasti-Corder Model PL 2000; Brabender, South Hackensack, New Jersey) with a barrel length : diameter ratio of 20:1, a screw compression ratio of 3:1, and a 2.95-mm-diameter circular die (die length : diameter ratio = 9.13). A constant barrel temperature profile of 40–90–100°C and a constant screw speed of 230 revolutions/min were used during extrusion. Further details about processing conditions and their effects on the resulting physical properties of the extrudates are provided by Ayadi et al. (2009). To ensure homogeneity within diets, all ingredients were combined in a laboratory-scale mixer (Model N50; Hobart Corp., Troy, Ohio) and were mixed for 10 min; each blend was then adjusted to a desired pre-extrusion moisture content of 60–65% by adding adequate amounts of water and mixing for an additional 15 min. After pellets exited the extruder die, they were cooled and dried at room temperature, crumbled, and then sieved to remove fines. Diets were stored at −20°C to prevent loss of ascorbic acid activity. Diets were analyzed for CP (method 2001.11 in AOAC 2009), crude lipid (method 2003.05 in AOAC 2009, modified by substituting petroleum ether for diethyl ether; Table 2), and amino acid profiles (ion exchange chromatography with post-column ninhydrin derivatization; methods 994.12 and 988.15 in AOAC 2009; Table 4). Tryptophan was estimated by using ingredient values from the National Research Council (NRC 1993). Digestible energy values were estimated based on the composition value of each ingredient multiplied by the physiological fuel values of 23.6, 39.5, and 19.2 kJ for proteins, lipids, and carbohydrates, respectively (NRC 1993; Table 2).

Approximately 500 juvenile yellow perch were placed in a 340-L, flow-through circular tank and were feed-trained on a commercial salmonid diet (45% CP, 16% crude lipid; 2.5-mm floating pellets; Silver Cup Fish Feed, Murray, Utah) for 160 d. After this holding period, 14 fish (initial individual weight [mean ± SE] = 19.1 ± 0.5 g) were randomly selected and stocked into each of twenty-four 110-L tanks (4 replicate tanks/diet) and were then acclimated to the reference diet (0/31.5) for a 14-d conditioning period. After conditioning, fish were given the experimental diets to apparent satiation two times

TABLE 5. Initial number of stocked yellow perch per tank ($n$), mean initial and final tank weights, absolute weight gain (AWG), and percent weight gain (PWG) for yellow perch that were fed diets containing various levels of distillers dried grains with solubles (DDGS) and soybean meal (SBM) for 126 d. Within a column, treatment means (SE in parentheses) with the same letter are not significantly different ($P \geq 0.05$); mean initial tank weight did not differ among treatments. An asterisk indicates that one mortality in a single tank within the given treatment occurred during the feeding trial.

| DDGS (%)/SBM (%) | $n$ | Mean initial tank weight (g) | Mean final tank weight (g) | AWG (g) | PWG |
|---|---|---|---|---|---|
| 0/31.5 | 14* | 253 (2) | 669 (25) zy | 417 (22) zy | 170 (6) yx |
| 10/26 | 14 | 257 (2) | 687 (14) zx | 430 (14) zx | 167 (5) zy |
| 20/20.5 | 14* | 258 (2) | 711 (39) yx | 453 (40) yx | 181 (11) yw |
| 30/15 | 14 | 256 (2) | 757 (47) x | 502 (45) x | 196 (16) xw |
| 40/9.5 | 14 | 255 (3) | 760 (17) x | 505 (17) x | 198 (7) w |
| 50/4 | 14 | 252 (4) | 606 (14) z | 354 (10) z | 140 (2) z |

per day for 126 d. Total tank weights were measured at the initiation of the experiment and at 14-d intervals thereafter (Table 5): all fish from one tank were netted, blotted to remove excess water, transferred to a tared container (filled with water from the tanks), and batch-weighed. At the end of the trial, fish were fasted for 24 h. Seven fish per tank were then euthanized, and the total length, whole-body weight, liver weight, and visceral weight of each individual were obtained to determine organosomatic indices and condition. Muscle plugs from two males and two females per tank were obtained and analyzed for CP and crude lipid levels (dry matter basis) to determine diet effects on muscle tissue composition. Crude protein levels were analyzed with a Tru-Spec CNS (carbon–nitrogen–sulfur) combustion analyzer (LECO Corp., St. Joseph, Michigan) by following standard methods (method 992.15 in AOAC 2009); crude lipid levels were determined by acid hydrolysis (method 948.15 in AOAC 2009) with a 50:50 mix of diethyl ether and petroleum ether for extraction. Moisture was determined via loss on drying (method 952.08 in AOAC 2009); a test portion was mixed with sand, partially dried with a steambath, and then completely dried in a mechanical convection oven at 100°C for 1 h. After an additional 48-h feeding period, the remaining 7 fish/tank were euthanized, and the lower half of the intestinal tract was stripped to obtain fecal samples for digestion analyses.

*Culture system*.—A common biological and mechanical filter system was used to recirculate water and maintain tank water quality characteristics at similar levels for the feeding trial. Each tank was supplied with recirculated water at an approximate rate of 1.7 L/min and was cleaned with a siphon when needed. A blower and diffusers provided continuous aeration. During the feeding trial, water temperature in the tanks ranged from 22.2°C to 24.0°C (mean ± SE = 23.2 ± 0.1°C). Foil-backed bubble wrap was used to insulate each tank in an attempt to reduce temperature fluctuations and minimize disturbances. A daily photoperiod of 14 h light : 10 h dark was maintained. Weekly measurements of nitrate (method 8039 in Hach 2008), nitrite (method 8153 in Hach 2008), and ammonia nitrogen (method 8038 in Hach 2008) were obtained by using a Hach Model DREL 2000 spectrophotometer (Hach Co., Loveland, Colorado). Weekly measurements of dissolved oxygen and temperature were obtained with a YSI Model 55 dissolved oxygen meter (Yellow Springs Instrument Corp., Yellow Springs, Ohio).

*Performance metrics*.—Growth performance was determined as absolute weight gain (AWG, g; final tank weight – initial tank weight), percent weight gain (PWG; 100 × [{final tank weight – initial tank weight}/initial tank weight]; Wu et al. 1996), feed conversion ratio (FCR; weight of feed consumed/total wet weight gain; Wu et al. 1996), and protein efficiency ratio (PER; 100 × [wet weight gain/CP consumed]; Wu et al. 1996). The FCR and PER were estimated by subtracting the weight of uneaten feed from the total weight of feed administered. One-hundred pellets per diet were randomly selected and weighed to determine the mean mass per pellet. Counts of uneaten pellets were performed at 30 min postfeeding in each tank to allow satiation but prior to pellet disintegration. To obtain an estimate of feed consumed, the number of uneaten pellets was multiplied by the mean mass per pellet for each diet, and the resulting value was then subtracted from the total mass of feed administered. This estimate of consumption was used to calculate FCR and PER. Condition was determined by use of the hepatosomatic index (HSI, %; 100 × [liver weight/weight of the whole fish]; Strange 1996), viscerosomatic index (VSI, %; 100 × [visceral weight/weight of the whole fish]; Strange 1996), and Fulton's condition factor ($K$; 100,000 × [fish weight/fish total length$^3$]; Anderson and Neumann 1996). Digestion was measured as apparent protein digestibility (APD, %; 100 × [{CP per g in feed – CP per g in feces}/CP per g in feed]; Lovell 1989). The gender ratio (GR; females per tank/males per tank) was also calculated for each tank.

*Statistical analyses*.—All variables (i.e., growth performance metrics, condition, muscle composition, and GR) were assessed with a one-way analysis of variance. If significant treatment effects existed, post hoc least-significant-difference tests were applied to detect differences between treatment means. Scatter plots and correlation analyses (Pearson's product-moment correlation) were used to determine whether linear correlations existed between physical properties of the extruded pellets (i.e., compressive strength and Hunter color values for luminosity [Hunter $L^*$] and red intensity [Hunter $a^*$]; described in further detail by Ayadi et al. 2009) and observed HSI and APD values. SYSTAT and SigmaPlot version 11 (SPSS, Inc., Chicago, Illinois) were used to perform all statistical analyses ($\alpha = 0.05$).

## RESULTS

Laboratory analyses indicated that the essential amino acids of arginine, leucine, tryptophan, and methionine plus cystine (total sulfur) in the experimental and reference diets met or were slightly lower than the recently estimated requirements suggested by Hart et al. (2010), whereas the remaining essential amino acids were lower than the estimated requirements (Table 4).

Absolute weight gain, PWG, and condition were significantly affected by the inclusion levels of DDGS plus SBM within the experimental diets (Tables 5, 6). Yellow perch that were fed the 40/9.5 diet had the highest apparent AWG and PWG and grew significantly larger than fish that were given the reference SBM diet (0/31.5); fish that received the 50/4 diet had significantly lower growth than fish in all other dietary treatments except 0/31.5 and 10/26 for AWG and 10/26 for PWG (Table 5). Likewise, HSI values were apparently influenced by the DDGS plus SBM inclusion level as fish that were fed the 40/9.5 diet had a significantly higher HSI value than fish that received any other diet (Table 6). In contrast, the $K$-value of fish that received the 50/4 diet was significantly lower than that of fish given any other diet; $K$-values for all other treatment groups were statistically similar (Table 6). Values of FCR, PER, and VSI did not statistically differ with varied amounts of DDGS plus SBM (Table 6).

TABLE 6. Feed conversion ratio (FCR), protein efficiency ratio (PER), viscerosomatic index (VSI), hepatosomatic index (HSI), Fulton's condition factor ($K$), and apparent protein digestibility (APD) for yellow perch that were given diets containing various levels of distillers dried grains with solubles (DDGS) and soybean meal (SBM) for 126 d. Within a column, treatment means (SE in parentheses) with the same letter are not significantly different ($P \geq 0.05$); FCR, PER, and VSI did not differ among treatments.

| DDGS (%)/SBM (%) | FCR | PER (%) | VSI (%) | HSI (%) | $K$ | APD (%) |
|---|---|---|---|---|---|---|
| 0/31.5 | 3.28 (0.06) | 31.1 (0.4) | 10.2 (0.1) | 1.5 (0.1) z | 1.14 (0.01) y | 49.4 (2.8) y |
| 10/26 | 3.37 (0.10) | 30.0 (0.9) | 10.6 (0.3) | 1.7 (0.1) zy | 1.13 (0.02) y | 47.6 (2.2) y |
| 20/20.5 | 3.25 (0.23) | 33.3 (3.0) | 9.9 (0.5) | 1.7 (0.1) zy | 1.16 (0.02) y | 51.3 (5.1) y |
| 30/15 | 2.94 (0.15) | 34.7 (1.8) | 10.5 (0.3) | 2.0 (0.03) zy | 1.15 (0.02) y | 46.2 (2.7) y |
| 40/9.5 | 2.85 (0.14) | 36.0 (1.8) | 10.6 (0.2) | 2.6 (0.3) x | 1.14 (0.004) y | 55.5 (4.0) y |
| 50/4 | 3.16 (0.17) | 30.7 (1.3) | 9.9 (0.2) | 2.1 (0.1) y | 1.07 (0.02) z | 69.7 (3.7) z |

Survival was near 100% across treatments; only two mortalities occurred during the experiment.

Muscle CP and crude lipid levels did not significantly differ among yellow perch that were given differing concentrations of DDGS plus SBM (Table 7). Similarly, GR did not differ across treatments (Table 7); therefore, it is assumed that the use of mixed-gender populations in tanks did not affect the analyses or comparisons of weight gain, condition, or feeding efficiency (i.e., FCR and PER).

Correlation analyses indicated that the level of combined plant constituents (i.e., increasing DDGS and decreasing SBM) and decreasing levels of Celufil (cellulose; U.S. Biochemical Corp.) in the experimental diets were significantly correlated with compressive strength ($r = 0.90$, $P = 0.02$), Hunter $L^*$ ($r = -0.98$, $P < 0.01$), and Hunter $a^*$ ($r = 0.98$, $P < 0.01$). The ratio of Celufil to plant proteins, which ranged from 0.0 to 0.54, may have been responsible for this strengthening effect, although this effect is confounded with the DDGS : SBM ratio, which ranged from 0.0 to 12.5. Further analyses indicated several significant correlations between the physical properties of the feeds and the yellow perch growth variables. A significant negative correlation ($r = -0.89$, $P = 0.02$) between HSI and Hunter $L^*$ was observed. A significant positive correlation ($r = 0.85$, $P = 0.03$) was detected between HSI and Hunter $a^*$. Apparent protein digestibility and compressive strength also exhibited a significant negative correlation ($r = -0.84$, $P = 0.04$).

TABLE 7. Gender ratios (GRs) of yellow perch in tanks and the crude protein (CP) and crude lipid concentrations (%, dry matter basis) in muscle samples from yellow perch that were fed diets containing various levels of distillers dried grains with solubles (DDGS) and soybean meal (SBM) for 126 d. Values are treatment means (SE in parentheses) for experimental diets. The GR and flesh composition were not significantly different ($P \geq 0.05$) among treatment groups.

| DDGS (%)/SBM (%) | GR (female : male) | CP (%) | Crude lipid (%) |
|---|---|---|---|
| 0/31.5 | 1.6 (0.4) | 95.3 (0.9) | 8.43 (0.80) |
| 10/26 | 0.8 (0.1) | 95.1 (0.4) | 8.95 (0.81) |
| 20/20.5 | 0.8 (0.1) | 94.5 (0.7) | 7.41 (1.39) |
| 30/15 | 1.1 (0.3) | 94.6 (0.4) | 6.09 (0.89) |
| 40/9.5 | 1.1 (0.3) | 94.8 (0.9) | 8.15 (0.97) |
| 50/4 | 0.9 (0.3) | 94.5 (0.3) | 8.42 (1.57) |

## DISCUSSION

The feeding trial results indicated that yellow perch are able to use relatively high levels of plant-based proteins as energy sources without negative impacts. Both AWG and PWG increased with increasing DDGS inclusion and decreasing SBM inclusion until the combined inclusion level exceeded 49.5%; however, feeding efficiency was not affected at any inclusion rate. Similar results have been reported for other cultured omnivorous species that were given beverage-based DDGS, such as tilapias *Oreochromis* spp. (Wu et al. 1996, 1997; Coyle et al. 2004) and channel catfish *Ictalurus punctatus* (Webster et al. 1992a, 1992b). Likewise, Kasper et al. (2007) administered increasing levels (0–73%) of SBM to juvenile female yellow perch and observed that weight gain and feed efficiency did not become depressed until SBM levels exceeded 50% and 40%, respectively. Those findings, along with the current results, suggest that yellow perch can use diets containing DDGS plus SBM at a combined level of 49.5% without compromised growth or feeding performance.

As levels of plant-based proteins increased, yellow perch condition either increased or was maintained at a level similar to that of fish given the reference diet. The HSI increased with increasing DDGS plus SBM until the combined inclusion level exceeded 49.5%. Mean $K$-values indicated that fish receiving the 50/4 diet experienced significantly lower condition than other treatment groups; the low $K$-value for the 50/4 treatment reflects the poor growth experienced by those fish.

Similar to the pattern observed for $K$-values, the APD was significantly different for fish that received DDGS plus SBM at a combined level greater than 50%. Nile tilapia *Oreochromis niloticus* that were given increasing levels of fuel-based DDGS from 17.5% to 27.5% maintained similar protein digestion coefficients (Schaeffer et al. 2010). Conversely, Cheng and Hardy (2004) incorporated fuel-based DDGS into the diets of rainbow trout and found that apparent retention of CP was statistically

similar between the reference diet (0% DDGS) and the 15% and 22.5% DDGS diets, whereas the 7.5% DDGS diet produced a significantly lower apparent CP retention than the reference diet (Cheng and Hardy 2004). In another study, apparent CP retention in rainbow trout varied with differing levels of SBM combined with 18.5% DDGS (Cheng et al. 2003). The conflicting results among studies indicate that more research is needed to determine the digestibility of DDGS among species and the potential effect of DDGS type (i.e., beverage- versus fuel-based DDGS).

Muscle composition (i.e., combined CP and crude lipid concentrations) of yellow perch that received varying levels of DDGS plus SBM indicated that the fish were able to incorporate these plant-based proteins into somatic tissue at similar rates. Likewise, VSI did not differ in relation to DDGS plus SBM inclusion rates, indicating that visceral deposition of lipid did not vary with diet composition. Therefore, it appears that increasing the amount of plant-based protein in diets does not alter lipid concentrations within the flesh and thus would be unlikely to cause off-flavor in fillets (Li et al. 2004).

As previously mentioned, several amino acids may have been deficient in the experimental diets in comparison with the requirements recently proposed by Hart et al. (2010). However, Hart et al. (2010) used whole-body essential amino acid concentrations and the quantified methionine requirement (Twibell et al. 2000) to provide a rapid assessment for predicting the remaining essential amino acid requirements. According to Hart et al. (2010), this method fails to account for some key factors, including assumed availability values and endogenous turnover of essential amino acids. Therefore, the estimated requirements may not adequately reflect the actual requirements of yellow perch. Several other studies have indicated yellow perch dietary requirements for arginine (1.4%; Twibell and Brown 1997) and lysine (1.3%; Twibell 2000) that were lower than those reported by Hart et al. (2010); these lower estimated requirements were satisfied by the experimental diets in the current study. The adequacy of growth responses and the virtual absence of mortality, disease, or deficiency signs suggest that the essential amino acid profiles provided by our experimental diets were adequate and that the amino acid requirements of yellow perch may be lower than reported by Hart et al. (2010).

Correlation analyses indicated that extrusion variables may provide insight into the overall condition and digestive capabilities of yellow perch that are given plant-based diets. Generally, color is not considered an important factor in aquaculture feeds from a feeding standpoint (Bjorck and Asp 1983); however, it has been suggested that color may be a general indicator of nutritional quality when one dietary ingredient is varied and the feed blends are extrusion-cooked, as temperature and pressure can alter proteins and starches (Kannadhason et al. 2010). Hunter $L^*$ and Hunter $a^*$ measure the ratios of luminosity to brightness and redness to greenness, respectively (Kannadhason et al. 2010). Therefore, the significant correlations between these color values and yellow perch HSI suggest a potential relationship; however, further research will be needed to determine whether the variation in these measures is linked by a common dietary mechanism that influences hepatic function. Likewise, the significant negative correlation between APD and the compressive strength of the pellets suggests that the ability of yellow perch to consume a plant-based feed pellet was influenced by the hardness of the pellets themselves—harder pellets reduced the fish's ability to utilize these feeds. To our knowledge, no other published studies have observed this phenomenon in fish; therefore, follow-up experiments should examine this potential relationship in greater depth.

In conclusion, our results indicated that juvenile yellow perch were able to use relatively high levels of plant-based proteins (i.e., DDGS plus SBM at up to 49.5%) as energy sources without negative impacts on growth, whereas performance drastically decreased when the fish were fed DDGS plus SBM at a combined inclusion level of 54%. These findings, along with those of Kasper et al. (2007), suggest that plant-based proteins can be used as the primary protein source in diets for yellow perch, but incorporation levels should not exceed 50% due to reduced growth and condition. It also appears that increasing levels of plant-based proteins do not negatively affect the muscle composition of yellow perch. Further research will be required to determine appropriate supplements for use when replacing FM with cereal grain–oilseed combinations in yellow perch diets and to more fully understand the dietary requirements of yellow perch. Such information will advance yellow perch culture by facilitating the production of low-cost, nutritionally complete diets. Feed extrusion parameters may be precursors for describing the potential effects of plant-based diets on acceptance and digestion by fish.

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