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Digestibility of Dry Matter, Protein, Lipid, and Organic Matter of Two Fish Meals, Two Poultry By-product Meals, Soybean Meal, and Distiller's Dried Grains with Solubles in Practical Diets for Sunshine Bass, *Morone chrysops* × *M. saxatilis*

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Abstract

Limited information is available on digestibility of nutrients in various practical ingredients used in diets for commercially important finfish species, such as hybrid striped bass. This information is especially needed for sunshine bass, *Morone chrysops* × *M. saxatilis*, to improve least-cost diet formulations and to allow effective substitution of feedstuffs. A study was conducted with large (867 g) sunshine bass to determine the apparent digestibility coefficients (ADCs) for moisture, protein, lipid, and organic matter (OM) in a variety of ingredients in floating, extrusion-processed, diets. The practical ingredients tested were menhaden (MEN) fish meal (FM), anchovy (ANCH) FM, pet-food grade poultry by-product meal, feed-grade poultry by-product meal, dehulled soybean meal (SBM), and distiller's dried grains with solubles (DDGS). Test diets consisted of a 70:30 mixture of reference diet to test ingredient with chromic oxide (1.0%) as the inert marker. Reference and test diet ingredients were mixed and extruded on a Wenger X85 single-screw extruder to produce floating pellets. The digestibility trials were conducted in twelve 1200-L circular tanks. Diets were randomly assigned to tanks of 30 sunshine bass and were fed once daily to satiation. Protein digestibility coefficients were significantly ($P < 0.05$) different among test ingredients and ranged from 86.42% for MEN to 64.94% for DDGS. Lipid ADCs were significantly different ($P < 0.05$) among test ingredients and ranged from 92.14% for MEN to 57.11% for SBM. OM ADCs were significantly different ($P < 0.05$) among test ingredients and ranged from 89.41% for MEN to 16.94% for DDGS. This information will assist in the formulation of more efficient, economical diets for sunshine bass.

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Striped bass (*Morone saxatilis*) and *Morone* hybrids are fourth in value and volume among domestically produced food fish (USDA/NASS 2006) and first in volume among U.S. recreational fisheries (NOAA/NMFS 2005). Farm gate prices have declined steadily, however, because of market pressure from increasing landings, domestic production, and imports (Carlberg et al. 2005). Because diet costs represent between 40 and 70% of the operating expenses of an aquaculture enterprise, reducing diet costs may increase profitability for producers and allow for further industry expansion.

While there have been several published reports on nutrient requirements and practical diet formulations for hybrid striped bass (HSB) (Webster 2002), many producers still feed diets containing high percentages of marine fish meal (FM) to ensure that essential amino acid and fatty acid requirements are met. Use of FM in aquaculture diets has come under scrutiny by various groups who have concerns about its long-term sustainability as a feed ingredient. Further, FM is the single most expensive macrofeed ingredient (currently costing between $1100 and 1400/ton in a volatile market) and is highly desired by other livestock industries. Hence, there are serious financial pressures to reduce the amount of FM in diets so as to minimize diet costs and thereby potentially improve profitability.

Nutritionists have devoted much research to finding alternative animal and plant protein sources as partial or total replacements for FM in diets for a variety of fish; however, there are limited data on nutrient digestibility of these ingredients in sunshine bass (*M. chrysops* × *M. saxatilis*) or palmetto bass (*M. saxatilis* × *M. chrysops*). Sullivan and Reigh (1995) reported protein, lipid, and energy digestibility coefficients for several practical diet ingredients for palmetto bass. Rawles and Gatlin (2000) reported nutrient and energy digestibility coefficients of two animal protein sources, seven plant protein sources, and a commercially blended protein ingredient for sunshine bass, while Gaylord et al. (2004) and Rawles et al. (2006) reported on the amino acid availability and gross nutrient digestibility of blood meal, poultry by-product meal (PBM), fish solubles, and four commercially blended protein products in sunshine bass.

While FM remains a primary protein source for fish diets, decreased use in the industry is forecast for the near future. Currently, aquaculture diets consume between 35 and 40% of the world's FM supply, but this is projected to reach 70% by 2015 (New and Wijkstom 2002). These projections, however, are based on old price and supply data; if current prices for FM continue, these projections are not likely to occur. One approach for partially, or totally, eliminating FM from aquaculture diets is to replace it with alternative, less expensive animal and/or plant by-products. Increased use of highly available and renewable by-products of the animal and crop industries can potentially increase profits for fish producers and allow continued expansion of the aquaculture industry.

One such product is PBM. However, use of PBM in fish diets sometimes results in reduced growth in carnivorous fish, especially when totally replacing FM diets. Nengas et al. (1999) stated that the reduced performance for some of the PBMs tested was because of insufficient amino acid content, as well as a lack of n-3 highly unsaturated fatty acids (HUFA). Yigit et al. (2006) observed that Black Sea turbot, *Psetta maeotica*, fed diets in which greater than 50% of FM protein was replaced by PBM exhibited reduced growth compared to fish fed a diet containing FM without PBM, possibly because of n-3 HUFA deficiency or amino acid imbalances in the diets containing PBM.

Soybean meal (SBM) is the most widely used plant protein source in aquafeeds because of its high protein content, satisfactory essential amino acid composition, competitive price, consistent quality, and steady supply. However, there are several disadvantages that accrue with the use of high percentages of SBM in diets for some fish, particularly carnivorous species. These include antinutritional factors (trypsin inhibitors and phytic acid) and palatability issues (Webster et al. 1992a).

Distiller's dried grains with solubles (DDGS) is the by-product resulting from condensing and drying at least 75% of the solids remaining from the distillation of ethyl alcohol from grain or grain mixtures. The attributes of DDGS offer several potential advantages to aquafeeds and include moderate protein (28–32%), lipid (9%), phosphorus, water-soluble vitamin concentrations, yeast and glucans that could potentially enhance immune function, and no antinutritional factors (Webster et al. 1993).

Cheng and Hardy (2003) noted that use of extrusion processing increased dry matter (DM), lipid, and energy digestibility values for rainbow trout, *Oncorhynchus mykiss*, but reduced protein and mineral digestibility coefficients. While there have been a limited number of studies to evaluate digestibility coefficients for HSB (Sullivan and Reigh 1995; Gallagher 1997; Rawles and Gatlin 1998; Rawles and Gatlin 2000; Rawles et al. 2006), few have used extruded diets. Because the majority of commercial diets fed to HSB are extruded (floating), it is important to determine digestibility coefficients for ingredients in diets that utilize this processing method. Furthermore, all previous digestibility coefficients have been determined in small juvenile HSB (<100 g); however, as the majority of diet is fed to larger fish during grow out, values from larger fish would be useful to both industry and the research community. Therefore, the objective of the current study was to determine the apparent digestibility of gross nutrients in four animal protein and two plant protein sources with potential for replacing FM in extruded diets for large (>800 g) sunshine bass.

Materials and Methods

Ingredients and Diet Preparation

Chromic oxide was used as an indigestible marker to estimate the apparent nutrient digestibility of six practical animal and plant ingredients (Table 1). The test ingredients included menhaden (MEN) FM, anchovy (ANCH) FM, solvent-extracted SBM, DDGS, feed-grade poultry by-product meal (PBM-feed), and petfood grade poultry by-product meal (PBM-pet). All ingredients were supplied by Rangen (Buhl, ID, USA). The reference diet was formulated to resemble a commercial diet that met or exceeded all known nutritional requirements of sunshine bass (Webster 2002; Table 2). Test diets were a 70:30 mixture of the reference diet and test ingredient (Cho et al. 1982).

All ingredients were ground to less than 0.5 mm in a pin mill (Alpine, Hosokawa Micron Powder Systems, Summit, NJ, USA), sized with a screener (Rotex, Cincinnati, OH, USA), and weighed to produce 80-kg batches of each diet. Chromic oxide was initially added to the wheat midds and SBM aliquots for each diet and mixed for 6 min. Remaining diet ingredients were then added to the previous mixture and subsequently mixed for an additional 6 min (No. 4A Buffalo mixer; John E. Smith's Sons Co., Buffalo, NY, USA). Diets were extruded on a pilot-scale, single-screw extruder (Wenger X85; Wenger, Inc., Sabetha, KS, USA) to produce 3-mm pellets. Water (12–14 kg/hr) and steam (11–13 kg/hr) were injected into the preconditioner and water (1–3 kg/hr) was injected into the barrel during extrusion. Water and steam levels varied because of compositional differences among test diets. Pellets were dried in a variable circulation batch dryer (Proctor and Schwartz, Division of Wolverine (MA) Corp., Horsham, PA, USA), air cooled, and top coated with lipid using a 22.7-kg capacity cement mixer (Kushland portable mixer;

TABLE 1. *Analyzed composition of the tested ingredients.*[1]

Ingredient	Dry matter (%)	Protein[2] (%)	Lipid[2] (%)	Organic matter[2] (%)
MEN	6.90 ± 0.32	66.02 ± 2.88	10.86 ± 0.19	78.18 ± 1.12
ANCH	7.40 ± 0.59	72.71 ± 3.40	9.40 ± 0.07	82.40 ± 2.80
SBM	10.70 ± 0.80	51.62 ± 1.79	3.81 ± 0.15	92.61 ± 1.93
DDGS	7.20 ± 0.42	28.77 ± 0.59	13.69 ± 0.22	95.37 ± 0.93
PBM-feed	4.80 ± 0.21	65.86 ± 1.25	15.44 ± 0.32	83.72 ± 2.54
PBM-pet	4.90 ± 0.40	68.14 ± 2.68	14.30 ± 0.41	88.22 ± 2.88

[1] Means (±SE) of analyses ($N = 3$).

[2] Dry-matter basis.

TABLE 2. *Composition of the reference diet.*

Ingredient	% as fed
Menhaden fish meal	30.00
Soybean meal	30.00
Wheat midds	15.05
Wheat flour	5.25
Corn meal	10.40
Menhaden fish oil	6.00
Dicalcium phosphate	1.00
Vitamin premix[1]	0.60
Mineral premix[2]	0.25
Stay-C (35%)	0.15
Choline chloride	0.30
Chromic oxide	1.00
Analyzed composition	
Moisture (%)	4.80
Protein[3] (%)	40.76
Lipid[3] (%)	11.76
Organic matter[3] (%)	87.92

[1] Vitamin premix was Abernathy vitamin premix #2 and supplied the following per kg of diet: biotin, 0.60 mg; B_{12}, 0.06 mg; E, 50 IU folic acid, 16.5 mg; myo-inositol, 132 mg; K, 9.2 mg; niacin, 221 mg; pantothenic acid, 106 mg; B_6, 31 mg; riboflavin, 53 mg; thiamin, 43 mg; D_3, 440 IU and A, 4399 IU.

[2] Rangen trace mineral mix for catfish containing 0.3 mg selenium/kg of diet added.

[3] Dry-matter basis.

TABLE 3. *Mean (±SE) dissolved oxygen, water temperature, total ammonia, nitrite, total alkalinity, and pH during two digestibility trials for sunshine bass.*

Morning dissolved oxygen (mg/L)	5.8 ± 0.12
Afternoon dissolved oxygen (mg/L)	11.8 ± 0.29
Morning water temperature (C)	26.4 ± 0.34
Afternoon water temperature (C)	28.5 ± 0.22
Total ammonia (mg/L)	0.18 ± 0.15
Nitrite (mg/L)	0.01 ± 0.002
Total alkalinity (mg/L)	107 ± 22
pH	8.8 ± 0.2

Kushland Products, Inc., Goldendale, WA, USA). The oil was added incrementally to each 22.7-kg batch of diet in the mixer.

Fish and Fecal Collection

Adult sunshine bass (867 g average individual weight) were stocked in twelve replicate, 1200-L fiberglass tanks at a rate of 30 fish/tank. Tanks were located in a wall-less outdoor building with translucent roofing panels to allow natural lighting. Water was continuously supplied (17.0 L/min) to each tank from a nearby reservoir supplied via a submersible pump.

Water quality data is presented in Table 3. Dissolved oxygen and water temperature were measured twice daily from a randomly chosen tank (0800 and 1600 h) with a YSI oxygen meter model 57 (YSI, Yellow Springs, OH, USA). Total ammonia and nitrite were measured three times weekly from a randomly chosen tank (1300 h) using a DREL/2000 spectrophotometer (HACH, Loveland, CO, USA). Total alkalinity was measured three times weekly using a digital titrator (HACH). pH was measured three times weekly (1300 h) using an electronic YSI model 60 pH meter. All measured water quality parameters were within acceptable limits for this species (Webster 2002).

Three tanks of fish were randomly assigned to each diet allowing three test diets and one reference diet to be fed per trial. Hence, two feeding trials were conducted sequentially in order to determine the digestibility of the six test ingredients. Between each feeding trial, fish were fed a commercial diet for 2 wk prior to new test diets being fed. In Trial 1, the three ingredients evaluated were MEN, PBM-feed, and PBM-pet. In Trial 2, the three ingredients evaluated were ANCH, SBM, and DDGS.

Diets were fed once daily (0800 h) to apparent satiation for 7 d prior to fecal collection. Fecal matter was collected by stripping approximately 7 h postprandial (Rawles and Gatlin 2000; Rawles et al. 2006). Fish were gently netted from the tanks and anesthetized by placing them in a 1000-L tank containing aerated water and 90 mg/L of tricaine methane sulfonate (MS-222; Argent Laboratories, Redmond, WA, USA) which has been determined at our laboratory as suitable for quickly anesthetizing sunshine bass. Fish were manually stripped onto treatment-labeled sheets of aluminum foil. Care was taken to ensure that urine, mucus, or water was not introduced to each sample. Fecal samples were immediately placed in glass jars, placed on ice for transport to the laboratory, frozen (−40 C), and stored until analysis.

Analysis of Ingredients, Diets, and Feces

DM, protein, lipid, and ash in ingredients, diets (Table 4), and feces were determined

TABLE 4. *Mean percentage dry matter, protein, lipid, and organic matter content of the experimental diets fed to market-size (≥800 g) sunshine bass.*[1]

Diet	Moisture	Protein[2]	Lipid[2]	Organic matter[2]
MEN	4.7	47.95	12.91	84.26
ANCH	4.1	49.74	13.03	85.71
SBM	4.6	43.71	11.11	88.78
DDGS	5.1	37.09	13.38	89.57
PBM-feed	5.2	47.68	14.24	86.39
PBM-pet	5.3	49.95	13.20	87.22

FM = fish meal.

[1] Diet designations are as follows: MEN = menhaden FM diet; ANCH = anchovy FM diet; SBM = soybean meal diet; DDGS = distiller's dried grains with solubles diet; PBM-feed = poultry by-product meal feed-grade; and PBM-pet = poultry by-product meal pet-food grade. Values are means of two replicates.

[2] Dry-matter basis.

according to standard methods (AOAC 2000). Chromium (Cr) was determined by a commercial analytical laboratory (Eurofins, Memphis, TN, USA). Total lipid in diets was determined by the acid hydrolysis method (AOAC 1995; procedure 954.02), whereas total lipid in fecal matter was determined by supercritical fluid extraction (LECO FA-100 Lipid Analyzer, LECO Corp., St. Joseph, MI, USA) as previously described (Johnson and Barnett 2003). Percentage organic matter (OM) was calculated as 100 minus the percentage ash. Apparent digestibility coefficients of nutrients (ADCNs) in the test ingredients were calculated according to Kleiber (1961) as recommended by Forster (1999):

$ADCN_{diet}$ = 100 − [100(% Cr in diet/% Cr in feces)/(% nutrient in feces/(% nutrient in diet)]; and

$$ADCN_i = \{(a = b) \times ADCN_{diet} - [(a)(ADCN_r)]\}/b,$$

where

$ADCN_{diet}$ = the ADC of the nutrient in the test diet;

$ADCN_r$ = the ADC of the nutrient in the reference diet;

a = [(1 − p)(nutrient content of the reference diet)];

b = (p)(nutrient content of the test ingredient); and

p = the proportion of the test ingredient in the test diet (or 0.30 in the present study).

Statistical Analysis

The ADCs for protein, lipid, and OM among the test ingredients evaluated within each trial were subjected to one-way analysis of variance using the PROC ANOVA program of SAS/STAT version 9.1 software (SAS 2006; SAS Institute, Inc., Cary, NC, USA). Differences in ADCs among the tested ingredients within each trial were determined using Duncan's multiple range test (Duncan 1955). All percentage data were transformed to arcsine values prior to statistical analysis (Zar 1984). Differences among ADC's of a particular nutrient in the different ingredients were considered significant at $P < 0.05$.

Results

In Trial 1, DM digestibility ranged from a low of 64.22% to a high of 79.17% for the three test ingredients (Table 5). The ADC of DM in MEN (79.17%) was not significantly higher than that of PBM-feed (64.22%) and PBM-pet (73.50%). Protein digestibility was significantly higher ($P < 0.05$) for MEN (86.42%) compared to that of PBM-feed (75.16%) but was not significantly different from PBM-pet (78.49%). There were no significant differences ($P > 0.05$) in ADC values for lipid and OM among the three diet ingredients (Table 5).

In Trial 2, DM digestibility was significantly higher in ANCH (59.74%) compared to DDGS (10.15%) but was not significantly different from the ADC for DM in SBM (39.77%). There were no significant differences in ADC values for protein and lipid among ANCH (79.44 and 82.32%, respectively), SBM (84.03 and 57.11%, respectively), and DDGS (64.94 and 68.72%, respectively); however, OM ADCs were significantly different ($P < 0.05$) among the three ingredients with ANCH (75.21%) being higher than SBM (55.98%) and DDGS (16.94%). OM ADC of SBM was significantly higher than the value for DDGS (Table 5).

Discussion

Fish Meals

Marine FMs are one of the most widely used protein sources in aquaculture diets for the past

TABLE 5. *Means (±SE) of apparent digestibility coefficients or dry matter, protein, lipid and organic matter of practical ingredients in floating extruded diets fed to market-size (≥800 g) sunshine bass.*[1]

Ingredient	Dry matter (%)	Protein (%)	Lipid (%)	Organic matter (%)
Trial 1				
MEN	79.17 ± 5.98^{a}	86.42 ± 1.51^{a}	92.14 ± 4.36^{a}	89.41 ± 4.00^{a}
PBM-Feed	64.22 ± 12.99^{a}	75.16 ± 3.46^{b}	86.87 ± 5.15^{a}	74.82 ± 9.75^{a}
PBM-pet	73.50 ± 7.87^{a}	78.49 ± 3.60^{ab}	92.00 ± 3.47^{a}	83.88 ± 5.79^{a}
Trial 2				
ANCH	59.74 ± 2.65^{a}	79.44 ± 0.90^{a}	82.32 ± 8.39^{a}	75.21 ± 1.23^{a}
SBM	39.77 ± 18.69^{ab}	84.03 ± 4.24^{a}	57.11 ± 7.70^{a}	55.98 ± 7.82^{b}
DDGS	10.15 ± 5.35^{b}	64.94 ± 8.38^{a}	68.72 ± 7.38^{a}	16.94 ± 4.49^{c}

MEN = menhaden FM diet; ANCH = anchovy FM diet; SBM = soybean meal diet; DDGS = distiller's dried grains with solubles diet; PBM-feed = poultry by-product meal feed-grade; and PBM-pet = poultry by-product meal pet-food grade.

[1] Values are means of three replicates. Means within column followed by a different superscript are different ($P < 0.05$).

30 yr because of their high protein, essential amino acid, and n-3 HUFA contents as well as their high nutrient digestibility and palatability. Moreover, numerous fish and crustacean meals have little or no antinutritional factors. In order to reduce or eliminate FM in aquafeeds, information on the availability of nutrients in alternate ingredients is essential so that substitutions can be made on a digestible, rather than gross, nutrient basis. Recent increases in the market price of FM dramatically underscore this need, and there are serious concerns about the long-term availability of FM for use in aquaculture diets, as other animal industries around the globe compete for this finite resource.

In the present study, ADCs for DM, protein, lipid, and OM in MEN were relatively high (79, 86, 92, and 89%, respectively) and agree with previous findings. For example, the digestibility of DM and protein in MEN for palmetto bass, *M. saxatilis* × *M. chrysops*, was 84 and 88%, respectively (Sullivan and Reigh 1995). Rawles and Gatlin (2000) reported ADCs for protein, lipid, and OM in MEN for small (50 g) sunshine bass of 81, 95, and 98%, respectively. Additionally, the digestibility of protein in MEN for sunshine bass appears similar to other piscivorous species. Gaylord and Gatlin (1996) reported a protein digestibility of 77% for MEN in red drum, *Sciaenops ocellatus*, while Hajen et al. (1993) reported a protein digestibility of 83% for MEN in Chinook salmon, *O. tshawytscha*.

To date, there are no published ADCs for ANCH in sunshine bass. The digestibility of protein in ANCH for sunshine bass is lower in the present study (79%) than that reported for salmonids, which ranged from 86 to 94% (Anderson et al. 1995; Sugiura et al. 1998, 2000) or for cod (92%), *Gadus morhua* (Tibbetts et al. 2006). Koprucu and Ozdemir (2005) reported ADCs for DM, protein, lipid, and OM in ANCH of 92, 91, 98, and 62%, respectively, in Nile tilapia, *Oreochromis niloticus*. Zhou et al. (2004) noted DM, protein, and lipid ADCs of 88, 96, and 96%, respectively, in Peruvian FM when fed to juvenile cobia, *Rachycentron canadum*. The lower digestibility of protein in ANCH reported in the present study compared to other values in the literature could be because of species or size differences. Nutrient digestibility has been shown to vary with fish size (Jobling 1994). At the same time, the ADCs for MEN and ANCH in the present study were lower than those reported for carnivorous species that require a higher dietary protein level (>45%) but similar to values reported for species with similar protein requirements as sunshine bass. Furthermore, nutrient digestibility of FMs is influenced by species composition, season of catch, and processing conditions (Tibbetts et al. 2006).

Soybean Meal

In the present study, market-sized sunshine bass efficiently digested protein from SBM (84%); however, ADCs for DM (40%) and lipid

(57%) in SBM were much lower than those observed in Nile tilapia with ADCs of 91, 87, 92, and 91% for DM, protein, and lipid, respectively (Koprucu and Ozdemir 2005). ADCs for protein and lipid in SBM were 84 and 81%, respectively, in cod (Refstie et al. 2006) but 91 and 92%, respectively, in cobia (Zhou et al 2004). Sullivan and Reigh (1995) noted that the digestibility of DM and protein in SBM was 45 and 80%, respectively, for palmetto bass, while Rawles and Gatlin (2000) found protein, lipid, and OM in SBM to be 77, 54, and 51% digestible, respectively, for sunshine bass. Papatryphon and Soares (2001) reported an ADC of 84% for protein in SBM when fed to 3-yr-old striped bass, *M. saxatilis*. Overall, these data support the notion that SBM may reduce the dependence on FM as the primary protein source in HSB diets.

Nevertheless, reduced nutrient bioavailability and growth have been reported in carnivorous fish fed diets containing high levels of SBM. Because diet intake is often not affected (Tibaldi et al. 2006), a disruption in nutrient digestion and/or absorption is suggested. The low digestibility of OM in SBM observed in this study (56%) may support this notion. Francis et al. (2001) suggested that oligosaccharides and nonstarch polysaccharides (NSPs) are responsible for the lower ADCs observed in soy ingredients through mechanisms involving nutrient binding with bile salts, changes in the viscosity and passage rate of digestate, and/or an obstruction of digestive enzymes.

Utilization of NSPs depends on solubility, with soluble NSPs being better utilized than insoluble (Amirkolaie et al. 2005). This may be because of increased time of the digesta in the intestine caused by soluble NSPs, which could stimulate the development of digestive bacteria. Tibaldi et al. (2006) reported that reduced nutrient digestibility of SBM in European sea bass, *Dicentrarchus labrax*, may be because of changes in digesta viscosity and passage rate caused by NSPs, rather than any adverse effects on mucosal enzymes. However, even soluble NSPs can slow passage rate in the gut, reduce mixing of digestive enzymes, increase endogenous losses of nutrients, thicken the water layer next to the intestinal mucosa, and reduce nutrient utilization (Storebakken 1985; Leenhouwers et al. 2006). Thus, reduced lipid digestibility in SBM to fish may be a result of indigestible soy alpha-galactosyl homologues of sucrose (e.g., oligosaccharides of raffinose), which are NSPs (Arnesen et al. 1990) and/or indigestible and soluble NSPs present in SBM such as saponins and isoflavones (Anderson and Wolf 1995). However, Leenhouwers et al. (2007) reported that there was little reduction in lipid digestibility in African catfish, *Clarias gariepinus*, fed diets containing various levels of NSPs. However, Leenhouwers et al. (2007) reported little reduction in lipid digestibility in African catfish, *C. gariepinus*, fed diets containing various levels of NSPs.

Diets in the present study were extruded in order to mimic industry conditions and improve the relevancy of results for production diets. Feed extrusion typically improves nutrient utilization of SBM in rainbow trout, *O. mykiss* (Pongmaneerat and Watanabe 1992, 1993; Barrows et al. 2007) and destroys some antinutritional factors as well (Marsman et al. 1997; Robinson et al. 2001; Barrows et al. 2007). On the other hand, other workers found no effect of either dietary inclusion level or treatment of SBM on protein and lipid digestibility in fish (Allan and Booth 2004; Tomas et al. 2005; Venou et al. 2006).

Poultry By-Product Meals

The present study represents one of the few reports of digestibility data for poultry products in *Morone* spp. and the first to compare two grades of PBM. Rawles et al. (2006) observed an ADC of 55% for protein in PBM fed to sunshine bass. In the same study, lipid ADC was 79% and OM ADC was 64% in PBM. Our results found much higher ADCs for PBMs and suggest little difference in the digestibility of nutrients in pet-food versus feed-grade PBM. Jobling (1994) stated that nutrient digestibility is affected by fish size. Hence, differences between the present study and that of Rawles et al. (2006) may be because of the fact that small sunshine bass (75 g) were fed in the previous study, whereas market-size fish were fed in the present study. However, Percival et al. (2001) reported no correlation between fish size and digestibility coefficients in Atlantic salmon, *Salmo salar*. Similarly, Refstie et al. (2006) found that ADCs of protein and lipid in 1- and 2-yr-old cod were not different among the tested ingredients. Thus, size of sunshine bass used may not be important. A more probable explanation to the differences in ADC values from the present study and Rawles et al. (2006) may be because of different sources of PBM used between the two studies. By-product meals can differ greatly among sources based upon the percentage and composition of the materials used to make the meal.

The higher ADC values for PBM in the present study for sunshine bass are in agreement with several other studies. Zhou et al. (2004) observed ADCs for protein, lipid, and DM of 91, 92, and 81%, respectively, in PBM fed to cobia, while Tibbetts et al (2006) observed 80% protein digestibility in PBM fed in test diets to cod. On the other hand, Dong et al. (1993) observed *in vivo* protein digestibility values that ranged from 64 to 74% in rainbow trout depending on source of the meal. Protein digestibility in PBM is highly variable among different grades, and numerous factors during manufacture can alter the composition and quality of the ingredient for animal diets (Parsons et al. 1997; Wang and Parsons 1998). Of particular concern is the proportion of feathers and other less digestible materials incorporated into the meal. Hence, Nengas et al. (1999) observed that PBM containing feathers had lower protein digestibility (60%) in gilthead seabream, *Sparus aurata*, compared to poultry meat meals without feathers (92%); moreover, the observed reduction in protein digestibility was associated with reduced growth when PBM replaced FM in the diet.

Lipid ADC for pet-food grade and feed-grade PBM was higher in the present study (92 and 87%, respectively) than that reported for sunshine bass (79%; Rawles et al. 2006) or red drum (59%; Gaylord and Gatlin 1996). Fish may digest and utilize lipid in ingredients containing saturated fatty acids less efficiently than ingredients containing HUFA (Olsen et al. 1998; Caballero et al. 2002). Thus, the digestibility of lipid in traditional livestock animal by-products may be reduced in sunshine bass because of relatively higher levels of saturated fatty acids when compared to FM (Rawles et al. 2006). However, it appears that both grades of PBM used in the present study were digested efficiently, as ADCs for all nutrients in PBM were not statistically different from those of FM.

The digestibility of OM in the two grades of PBM tested in this study followed similar trends to the digestibility of protein, lipid, and DM in those products. This is similar to other work in *Morone* spp. (Sullivan and Reigh 1995; Rawles and Gatlin 2000; Rawles et al. 2006). Although higher numerical values were determined for OM digestibility in pet-food grade (84%) as opposed to feed-grade PBM (75%), these values were not statistically different. Nevertheless, the ADCs of OM in both PBMs of the current study were higher than that reported earlier for sunshine bass (64%; Rawles et al. 2006).

The differences noted in the digestibility of nutrients in PBM among different carnivorous fish could explain the variation in performance reported among previous FM replacement studies and underscore the value of determining nutrient availabilities and formulating diets on an available, rather than gross, nutrient basis. Webster et al. (1999, 2000) observed conflicting results for sunshine bass fed diets in which PBM totally replaced FM. Equivalent growth was observed in one study (Webster et al. 1999), while reduced growth and feed efficiency were observed in a second study, when PBM totally replaced FM in diets fed to sunshine bass (Webster et al. 2000). Greater consistency in the quality of PBMs on the market is essential for formulating reliable fish diets, which utilize PBM as a partial or total substitute for FM.

Distiller's Dried Grains with Solubles

This is the first published report to determine the digestibility of DDGS for sunshine bass. Cheng and Hardy (2004a) were first to report the digestibility for fish of DDGS: protein and lipid ADCs of DDGS were 90 and 82% digestible, respectively, for rainbow trout and were higher than those found in this study. In the current study, ADCs for protein and lipid of DDGS were moderate (65 and 69%, respectively) and lower than those for protein and lipid in MEN. These results suggest that sunshine bass can effectively digest nutrients in an ingredient with moderate protein (28–32%) and higher carbohydrate than typical protein supplements. On the other hand, ADCs for DM and OM in DDGS were low (10 and 17%, respectively) for sunshine bass. The digestibility of OM in ingredients with high percentages of carbohydrates may be reduced in carnivorous fish because of limited carbohydrate digestion (Hemre et al. 1989; Grisdale-Helland and Helland 1998). However, the fact that protein and lipid digestibility were high to moderate suggests that extrusion processing may have improved availability of these nutrients for sunshine bass. Rawles and Gatlin (2000) reported that protein, carbohydrate, gross energy, and OM in corn are poorly digested by sunshine bass, possibly because of high percentages of indigestible carbohydrates such as lignin and cellulose which are resistant to improved digestibility by extrusion processing.

DDGS have been added to fish diets since the late 1940s; however, inclusion levels have been generally low. Results from the use of moderate (>15%) inclusion levels of DDGS in channel catfish, *Ictalurus punctatus*, tilapia, and rainbow trout have been promising (Tidwell et al. 1990; Webster et al. 1991, 1992a, 1992b, 1993; Coyle et al. 2004; Cheng and Hardy 2004b). Webster et al. (1992a) stated that channel catfish fed a diet in which FM was replaced by a combination of plant protein sources that included DGGS, instead of one protein source, may allow for complete FM replacement.

The inclusion of DDGS in warmwater fish diets extends beyond omnivorous fish diets. Webster et al. (1999) found that sunshine bass fed a diet containing no FM, 29% SBM, 29% meat and bone meal (MBM), and 10% DDGS had similar final weight, percentage weight gain, survival, specific growth rate (SGR), and feed conversion ratio (FCR) compared to fish fed a diet containing 30% FM. However, sunshine bass fed a diet containing 30% SBM and 31% MBM had significantly lower ($P < 0.05$) growth performance and higher FCR compared to fish fed the diet containing 30% FM. Hence, use of DDGS in sunshine bass diets may have improved palatability and essential amino acid composition of the SBM/MBM diet (Webster et al. 1992a).

In summary, all ingredients tested in this study appear suitable for sunshine bass diets. Both varieties of FM (MEN and ANCH) appear to be well digested by sunshine bass with high ADCs for protein and lipid. Likewise, protein digestibility for SBM in sunshine bass was not significantly different than that of the two types of FM, although lower digestibility for lipid was found. Both grades of PBM tested in the present study showed few differences and suggest that greater use of the lower costing feed-grade PBM may be warranted. However, wide differences in quality from different sources of PBM indicate that further study is required. While the use of DDGS in sunshine bass diets appears warranted, its inclusion level should be cautious and perhaps complimentary to other protein sources because of the lower digestibility of some nutrients when compared to other ingredients (Webster et al. 1992a).

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