

Effects of Commercial Fish Meal Analogue and Menhaden Fish Meal on Growth of Red Drum Fed Isonitrogenous Diets

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Abstract.—Four diets were formulated to determine the effectiveness of supplementing a commercially available protein source (Pro-Pak[®] from H. J. Baker and Brothers, Inc.) for menhaden fish protein (Special Select[®] from Zapata Haynie Corp.), in diets for red drum *Sciaenops ocellatus*. The diets were formulated to be isonitrogenous, each contained 45% total protein. Protein from soybean meal and wheat gluten was kept constant; Pro-Pak replaced 0, 25, 50, or 75% of the menhaden fish meal on an equal protein basis. In the first 8-week growth trial, which used satiation feeding, positive results from high fish meal diets were observed; percent weight gain ranged from 630 to 830%, and there was near 100% survival. In a basal diet containing 40% fish meal, the replacement of 50% of the fish protein with Pro-Pak resulted in minimal changes in growth and feed consumption. The replacement of 75% of the fish protein in the basal diet (diet 4) resulted in reduced performance of the fish. The second growth trial confirmed reduced growth rates of fish fed diet 4 under fixed feeding conditions, confirming nutritional differences between the test ingredients. Based on the results of this study, with appropriate restrictions, Pro-Pak should be considered an acceptable ingredient in practical diets for red drum.

Red drum *Sciaenops ocellatus* is an important fish for both aquaculture and the sport fishery. The species is currently cultured along the Gulf of Mexico and the southern Atlantic coast of the United States, as well as in several Central American and Asian countries. Production of high quality fish, whether for stocking or consumption, at a minimum cost is needed to enhance the economic viability of red drum aquaculture. Fish feed represents the largest single cost for culture of most fish, and protein is the most costly component; therefore, there is a need for information about sources of protein that yield acceptable growth and survival at the lowest cost.

With the exception of studies on the use of soybean meal (Reigh and Ellis 1992; Davis et al. 1995), little work has been conducted on alternate protein sources as replacements for menhaden fish meal in practical diet formulations for red drum. Pro-Pak[®] (H. J. Baker and Brothers, Inc.) is a blend of animal by-products that was designed for the poultry industry as a substitute for fish meal. Because it has a similar nutrient profile to that of fish meal and is generally lower in price than menhaden fish meal (US\$275–300/ton for Pro-Pak versus \$365–395/ton for Zapata Haynie Corp.'s menhaden product, Special Select[®]) it may be suitable for inclusion in red drum diets. The present study

was designed to evaluate Pro-Pak as a replacement for fish meal in practical diets for red drum.

Methods

Two growth trials were conducted to determine the effectiveness of substituting Pro-Pak for the menhaden fish meal protein in Special Select in practical diets designed for juvenile red drum. In preparation for these studies, twelve 180-L tanks were connected with a semiclosed recirculating-water filter system, consisting of a circulation pump and a rapid-rate sand filter with 48-mm effective size silica sand and a common biological filter. Photoperiod was set at 12 h light : 12 h dark. Juvenile red drum were hand-graded to a uniform size and stocked in excess in each of the 12 tanks for acclimation periods of 1 week. During this time they were fed by hand to satiation twice daily with trout and salmon starter feed (Rangen, Inc., Buhl, Idaho). At the end of the acclimation periods, fish were sorted for uniformity of size, and the tanks were stocked to a uniform biomass load with equal numbers of fish.

In the first growth trial, 18 fish (mean weight, 12.6 g/fish) were stocked into each tank and diets were assigned to three replicate tanks per treatment. Twelve fish from the remaining population were randomly collected and frozen for subsequent biochemical analyses. Throughout the 8-week growth trial, the fish were fed by hand to satiation

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TABLE 1.—Chemical and amino acid analyses^a of Special Select, a menhaden fish meal product, and Pro-Pak, a commercial protein source, that were used in this study.

Component	Special Select	Pro-Pak
Moisture	10.86	7.39
Fat	7.33	9.63
Ash	18.24	17.88
Calcium	5.23	5.10
Phosphorus	3.10	3.07
Salt	0.87	0.93
Crude protein	63.30	62.60
Pepsin digestibility	96.05	93.77
Methionine	1.84	1.64
Cystine	0.62	1.06
Lysine	4.73	3.57
Phenylalanine	2.21	2.32
Leucine	4.28	4.11
Isoleucine	2.65	2.04
Threonine	2.92	2.47
Valine	2.88	3.25
Histidine	2.14	2.07
Arginine	4.09	3.92
Glycine	4.34	5.56
Aspartic acid	6.31	4.69
Serine	2.79	3.13
Glutamic acid	8.28	6.99
Proline	2.98	3.95
Hydroxyproline	0.00	1.68
Alanine	3.96	4.00
Tyrosine	2.09	1.93

^a As reported by New Jersey Feed Laboratory, Trenton, New Jersey. Determinations were made in accordance with methods of the Association of Official Analytical Chemists (AOAC 1984) and are reported as g/100 g sample weight.

twice per day according to the methods described by Davis et al. (1995). Consumption was recorded daily, and fish were counted and weighed weekly. Salinity, temperature, and dissolved oxygen were measured daily; ammonia, nitrite, and pH were measured three times per week. Water quality (mean \pm SD) was maintained as follows: temperature, $28.4 \pm 1.0^\circ\text{C}$; salinity, $34.7 \pm 5.4\text{‰}$; dissolved oxygen 5.7 ± 0.5 mg/L; total ammonia nitrogen, 0.13 ± 0.08 mg/L; nitrite-nitrogen 0.13 ± 0.16 mg/L; pH, 7.6 ± 0.23 .

Pro-Pak was obtained from H. J. Baker and Brothers, Inc., New York, New York, and the menhaden fish meal (Special Select) was obtained from Zapata Haynie Corp., Hammond, Louisiana. Biochemical analyses of the two meals are presented in Table 1. All diets were formulated to be replete with reference to known nutrient requirements of red drum (Daniels and Robinson 1986; Davis and Robinson 1987; Brown et al. 1988; Williams and Robinson 1988; Ellis and Reigh 1991; Moon and Gatlin 1991; Craig and Gatlin 1992; Serrano et al. 1992; Lochmann and Gatlin 1993a, 1993b) and contained 45% total protein (Table 2), with 61.5%

TABLE 2.—Composition (g/100 g dry weight) of the test diets.

Ingredient	Diet 1	Diet 2	Diet 3	Diet 4
Menhaden fish meal (Special Select)	40.00	30.00	20.00	10.00
Pro-Pak	0.00	10.71	21.41	32.12
Nurish 1350 ^a	10.00	10.00	10.00	10.00
Soybean meal ^b	12.50	12.50	12.50	12.50
Menhaden fish oil ^c	3.80	3.80	3.80	3.80
Wheat gluten ^d	5.00	5.00	5.00	5.00
Wheat starch ^d	24.80	24.09	23.39	22.68
Trace mineral premix ^e	0.50	0.50	0.50	0.50
Vitamin premix ^f	3.00	3.00	3.00	3.00
Stay C ^g	0.10	0.10	0.10	0.10
KH ₂ PO ₄ ^h	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00

^a Soy protein isolate: Protein Technologies International, St. Louis, Missouri.

^b Consists of 44% protein, solvent extracted; Producers Cooperative Association, Bryan, Texas.

^c Zapata Haynie Corp., Hammond, Louisiana.

^d United States Biochemical Corp., Cleveland, Ohio.

^e All values are g/kg premix; cobalt chloride, 0.004; cupric sulfate pentahydrate, 0.250; ferrous sulfate, 4; magnesium sulfate heptahydrate, 28.398; manganous sulfate monohydrate, 0.650; potassium iodide, 0.067; sodium selenite, 0.010; zinc sulfate heptahydrate, 13.193; filler, 53.428.

^f All values are g/100 g premix; thiamin HCL, 0.5; riboflavin, 3; pyroxidine HCL, 1; DI Ca-pantothenate, 5; nicotinic acid, 5; biotin, 0.05; folic acid, 0.18; vitamin B12, 0.002; choline chloride, 100; inositol, 5; menadione, 2; vitamin A acetate (20,000 IU/g), 5; vitamin D3 (400,000 IU/g), 0.002; *dl*-alpha-tocopherol acetate (250 IU/g), 8; alpha-cellulose, 865.266.

^g L-ascorbyl-2-polyphosphate; Hoffman-LaRoche Inc., Nutley, New Jersey.

^h Spectrum Chemical Manufacturing Corp., Gardendale, California.

of the protein derived from menhaden fish meal and Pro-Pak. Diets were formulated with fish protein: Pro-Pak protein ratios of 1:0, 3:1, 1:1, and 1:3.

Feed was prepared during the acclimation period. Coarse ingredients were ground with a laboratory hammer-type mill and a number-40 screen was used. Dry ingredients and oil were mixed in a food mixer (Hobart Corp., Troy, Ohio) for 20 min. Hot water was then blended into the mash to attain a consistency appropriate for pelleting. Each feed was extruded through a 3-mm die in a meat grinder, and the pellets were dried to a moisture content of less than 10%. Protein content was confirmed by micro-Kjeldahl analysis (Ma and Zuazago 1942). Diets were stored in a refrigerator and were crumbled and sieved to the desired size before use.

At the conclusion of the first growth trial, four fish were randomly selected from each tank for a determination of percent visceral fat and for fillet samples. A fish and its dissected visceral fat were

TABLE 3.—Response of red drum to diets containing graded levels of Pro-Pak over the 56-d feeding trial. Values are means of three replicates and those within the same column followed by a common letter are not significantly different ($P > 0.05$).

Diet	Fish meal (%)	Weight ^a		Survival (%)	Consumed feed ^b (g)	FER ^c (%)	PER ^d (%)
		Final (g)	Gain (%)				
1	40	114.9 z	829.1 z	100.0 z	88.6 z	115.9 z	47.0 z
2	30	117.1 z	832.3 z	98.1 z	93.6 z	111.6 z	43.1 z
3	20	107.2 zy	728.4 zy	98.1 z	85.3 z	110.4 z	40.5 z
4	10	91.8 y	629.2 y	100.0 z	71.5 y	110.5 z	40.3 z
Pooled SE		4.9	36.2	1.3	3.5	2.3	2.0

^a Initial mean weight of fish was 12.6 g.

^b Average total dry weight of feed consumed per fish during the growth trial.

^c Feed efficiency ratio = $100 \times (\text{g wet weight gain/g dry weight feed consumed})$.

^d Protein efficiency ratio = $100 \times (\text{dry weight of protein consumed/protein gain})$.

weighed and percent visceral fat was determined. A single skinless fillet from each fish was removed, pooled by tank, homogenized, and frozen for subsequent proximate analysis. An additional four fish from each tank were homogenized and frozen for subsequent whole-body analyses. Samples from the start of the experiment were frozen at -70°C and then analyzed with samples obtained at the conclusion of the growth trial. During analyses, short-term frozen storage was maintained at -10°C . Dry matter was determined by drying to constant weight at 100°C . Protein content was determined by the micro-Kjeldahl method (Ma and Zuazago 1942). Percent lipid was determined for the whole-fish samples by the method described by Folch et al. (1957). All analyses were conducted with duplicate subsamples.

The second growth trial was designed to evaluate diets 1 and 4 under both fixed and satiation feeding conditions. The experimental protocol was as previously described, with the following modifications. After the initial acclimation period, the fish were stocked at a density of 15 fish/tank (mean weight, 13.5 g/fish). Based on the results of the first growth trial, diet 4 appeared to have reduced palatability; consequently, all fish were conditioned to diet 4 at a fixed feed rate (5%) over an additional week. Once the fish were conditioned to diet 4, they were weighed, treatments were assigned, and the 55-d growth trial was initiated. Satiation feeding was conducted as previously described, and average daily consumption rates were calculated, based on weekly weights and feed intake. This average daily consumption rate was used, in combination with visual observations of the fish, to adjust the fixed feeding rate for the following week. Although feeding rates were decreased over the experiment (from 5% to 3.5%), they were held constant for both treatments on a

weekly basis. In general, no residual feed was observed in the tanks after feeding. When residual feed was found (three occurrences), the feed was collected, dried, and used to correct the feed consumption value for that day. Water quality variables (mean \pm SD) were maintained as follows: temperature, $28.5 \pm 1.2^{\circ}\text{C}$; salinity, $27.8 \pm 1.9\text{‰}$; dissolved oxygen 5.7 ± 0.4 mg/L; total ammonia nitrogen, 0.16 ± 0.08 mg/L; nitrite-nitrogen, 0.21 ± 0.24 mg/L; pH, 7.7 ± 0.1 .

Data from the first feeding trials were analyzed with a one-way analysis of variance and Student-Newman-Keuls' multiple-range test (Steel and Torrie 1980) to determine significant differences ($P \leq 0.05$) among treatment means. Data from the second experiment were analyzed by an analysis of covariance, with mean initial weights of the fish as the covariate. All statistical analyses were performed with SAS statistical software (SAS Institute 1988).

Results

The first growth trial was conducted through the 8 weeks without interruption, water quality problems, or disease problems. Mean values for final weight, percent weight gain, survival, food consumption, feed efficiency ratio (100-g wet weight gained/g dry weight feed consumed), and protein efficiency ratio (100-dry weight of protein consumed/protein gain) for fish fed the various diets are presented in Table 3. Mortality was minimal, with no significant differences in survival observed between treatment means. Final weight and percent gain were significantly greater for fish fed diets 1 and 2 than for fish fed diet 4 (Table 3).

All diets were readily consumed; however, diets containing low percentages of menhaden fish meal were consumed by the fish at reduced levels. The total average consumption of diet 4 fell signifi-

TABLE 4.—Percent visceral fat and proximate composition of fillet and whole-body samples of red drum fed the test diets over a 56-d growth trial. Values are means of three replicate samples, each consisting of a pooled sample from four fish. Numbers within the same column followed by a common letter are not significantly different ($P > 0.05$).

Diet	Fillet			Whole body		
	Visceral fat	Dry matter	Protein ^a	Dry matter	Protein ^a	Lipid ^a
1	0.36 z	22.3 z	86.5 z	26.1 zy	68.6 z	16.5 z
2	0.60 z	22.6 z	86.4 z	26.4 z	64.7 z	15.8 z
3	0.47 z	21.8 y	86.7 z	25.0 zy	65.7 z	16.2 z
4	0.51 z	21.9 y	89.1 z	24.6 y	65.6 z	14.9 z
Pooled SE	0.095	0.12	1.14	0.39	2.9	0.84

^a Expressed on a dry-weight basis.

cantly below the other diets (Table 3). In the first growth trial, the poor response of fish to the low fish meal diet (diet 4) was apparent within 3 weeks of initiation of the experiment. It should be noted that at that time, the average weight and feed intake of the fish offered the low fish meal diet were significantly lower than those of fish fed all other test diets. At the conclusion of the growth trial, the decreases in feed intake and growth rate were accompanied by decreases in both feed and protein conversion efficiencies (Table 3), but no statistical differences were apparent.

Changes were minimal in visceral fat content of the fish and proximate analysis of fillet and whole-body samples of fish fed the various diets (Table 4). Visceral fat ranged from 0.36 to 0.60% for fish fed on diets 1 and 2, respectively, with no significant differences or observable trends noted between dietary treatments. Percent dry matter of the fillet for fish fed diets 3 and 4 were 21.8 and 21.9%. These values were significantly lower than the 22.3 and 22.6% dry matter observed for fish fed diets 1 and 2. Dry matter content of the whole body for fish fed diet 2 (26.4%) was significantly higher than that of fish fed diet 4 (24.6%), but not significantly different from fish fed diets 1 and 3. Protein content of the fillet and whole-body samples ranged from 86.4 to 89.1% and from 64.7 to 68.6%, respectively, with no significant differences observed among treatments. Lipid content of whole-body samples ranged from 14.9 for fish fed diet 4 and to 16.5% for fish fed diet 1; there were no significant differences among dietary treatments.

The second growth trial was designed to reevaluate diets 1 and 4 under both fixed and satiation feeding conditions. The growth trial was con-

TABLE 5.—Response of red drum to diets 1 and 4 under satiation and fixed feeding conditions over a 55-d feeding period (trial 2). Values are means of three replicates. Numbers within the same column and feeding condition followed by a common letter are not significantly different ($P > 0.05$).

Regime and diet	Fish meal (%)	Final weight, g (% gain) ^a	Survival (%)	Consumed feed ^b (g)	FER ^c (%)
Satiation					
1	40	126.3 z (649.7)	100.0 z	105.7 z	103.8 z
4	10	115.5 y (551.2)	100.0 z	97.3 y	100.4 z
Pooled SE		2.2		1.8	2.5
Fixed					
1	40	126.1 z (615.6)	100.0 z	102.6 z	108.2 z
4	10	114.1 y (545.4)	97.7 z	92.6 y	104.0 z
Pooled SE		1.7	1.3	1.3	1.3

^a Initial weights (grams) for fish fed diets 1 and 4 under satiation conditions were 16.8 and 17.4, respectively; for fish fed diets 1 and 4 under restricted (fixed) conditions, initial weights were 18.0 and 17.7.

^b Average total dry weight of feed consumed per fish during the growth trial.

^c Feed efficiency ratio (FER) = $100 \times (\text{g wet weight gain/g dry weight feed consumed})$.

ducted through the 55-d period without interruption or water quality problems. Initial weights were used as a covariate for the evaluation of final weights and consumed feed. Mean values for final weight, survival, food consumption, and feed efficiency ratio for fish fed the various diets are presented in Table 5. Mortality was minimal, with no significant differences in survival among treatments. For both feeding regimes, final weight, percent weight gain, and total feed consumed per fish were significantly higher for fish offered diet 1. There were no significant differences in feed efficiency ratios under either feeding condition.

Discussion

Under the reported conditions, the replacement of 50% of the protein originating from fish meal in the basal diet containing a high level (40%) of fish meal resulted in minimal changes in growth and feed consumption. However, the replacement of 75% of the dietary fish protein resulted in reduced performance of the fish. The poor response to the low fish meal diets may have been caused by reduced palatability or by nutritional changes in the diets. Partial rejection (increased orobranchial manipulation followed by consumption) and

reduced feed intake that occurred throughout the course of the studies and appeared to be associated with diets containing the lowest levels of fish meal, indicated differences in palatability between the two protein sources. Complete rejection of the feed, as had been observed in studies of alternate protein sources such as soybean meal (Reigh and Ellis 1992), did not occur. The decreased feed consumption and, consequently, decreased growth rates of the fish fed diet 4 were apparent by day 21 of the first growth trial. Similar results were seen in the second trial, despite the use of diet 4 as a preconditioning diet. Reduced growth rates of fish fed diet 4 also occurred under fixed feeding conditions, indicating a difference in the nutritional quality of the two protein sources.

Under the reported conditions, the feed efficiency ratio ranged from 100.4 to 115.9% and the protein efficiency ratios were above 40%. These values are comparable to values previously observed for red drum of this size-class with this diet type and feeding strategy (Jirsa 1994; Davis et al. 1995). Although there was a general decrease in protein efficiency corresponding to increases in Pro-Pak in the test diets, the differences were not significant. These results, in combination with differences in pepsin digestibility values, may indicate differences in digestibility; hence, further evaluations of the digestibility and nutrient limitations of Pro-Pak are warranted.

In their study of the effects of dietary soybean and fish-protein ratios on growth and body composition of red drum fed isonitrogenous diets, Reigh and Ellis (1992) reported body composition decreased in moisture and protein levels when fish meal levels were increased in the diets. They related these differences mostly to digestibility of protein in soybean and fish meals, along with the energy availability from various sources. In this study, there were no significant differences in the protein content of whole-body or fillet samples, lipid content of whole-body samples, or percent visceral fat of fish fed the various diets. Although there were clearly differences in the nutritional quality of the two protein sources (Table 1), the differences appear to be within the tolerance of red drum.

Based on the results of this study, with appropriate restrictions, Pro-Pak is acceptable for partial replacement of menhaden fish meal in practical diets for red drum. However, under the reported conditions, Pro-Pak does not appear to have acceptable characteristics to support maximum growth rates when low levels of menhaden fish

meal are used. Further research designed to evaluate alternate protein sources and the use of attractants to maintain maximum consumption and growth rates of red drum while reducing the quantity of marine protein in formulated diets is warranted.

Acknowledgments

This research was supported in part by the Sid W. Richardson Foundation. Biochemical analyses of the test ingredients were supported by H. J. Baker, Inc. Mention of tradenames or proprietary products does not constitute an endorsement by The University of Texas at Austin and does not imply its approval to the exclusion of other products that may also be suitable. This is the University of Texas at Austin Marine Science Institute contribution 962.

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