EVALUATION OF SEAFOOD PROCESSING WASTES IN PREPARED FEEDS FOR RED DRUM (*Sciaenops ocellatus*)

A Thesis

by

BENJAMIN MARK PERNU

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2011

Major Subject: Wildlife and Fisheries Sciences

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Approved by:

Chair of Committee,	Delbert M. Gatlin III
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ABSTRACT

Evaluation of Seafood Processing Wastes in Prepared Feeds for Red Drum (*Sciaenops ocellatus*). (May 2011)

Benjamin Mark Pernu, B.S., The University of Tulsa

Chair of Advisory Committee: Dr. Delbert M. Gatlin III

High feed costs and increasing demand for fishmeal have intensified the search for alternative protein sources which are needed to allow world aquaculture to continue expanding. A severely underused marine resource is processing wastes of various types of seafood, which are often disposed of at great cost. Therefore, this study was conducted to evaluate three different types of seafood processing wastes as potential feed ingredients for the red drum (*Sciaenops ocellatus*).

The three processing wastes evaluated were heads and shells from Penaeid shrimp, and viscera and skeletal remains from filleted black drum (*Pogonias cromis*) and channel catfish (*Ictaluras punctatus*). These wastes were blended with soybean meal in a 40:60 ratio, dry extruded and dried to produce stable ingredients. All three byproduct meals produced had crude protein levels ranging from 45 to 50%. Two feeding trials were conducted to evaluate the different processing waste byproduct meals in comparison to menhaden fishmeal. A digestibility trial was conducted with sub-adult red drum which led to the computation of apparent digestibility coefficients (ADCs) for organic matter, protein, lipid and energy for each of the byproduct meals. Each byproduct meal had relatively high ADC values that were generally similar to those of menhaden fishmeal.

A comparative growth trial with red drum was then conducted in which experimental diets were formulated with the three byproduct meals replacing menhaden fishmeal on an equal-digestible-protein basis at levels of 65%, 80%, or 95%.

Juvenile red drum were fed the various diets for 8 weeks in a brackish (6 $\pm$ 1 ppt) water recirculating system after which weight gain, survival, feed efficiency, as well as whole-body proximate composition and condition indices were measured. All three of the byproduct meals could replace up to 65% of the protein provided by fishmeal without adversely affecting performance of red drum. However, the shrimp byproduct consistently provided the highest performance values at 80% replacement. The catfish byproduct yielded the lowest fish performance at all levels. This study indicates that dry extrusion of seafood processing wastes can be used to replace a considerable amount of fishmeal in feeds for red drum.

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TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

Feed is the single largest variable cost in aquaculture (Naylor et al., 2000), accounting for between 40 and 60 percent of total operating costs. Many aquacultured species, such as the red drum (*Sciaenops ocellatus*), require relatively high protein levels in prepared feed. Fishmeal is typically the most desirable protein source from a nutritional perspective, but it is also very expensive. As aquaculture worldwide continues to rapidly expand, demand for fishmeal and fish oil has begun to skyrocket, and the price will only continue to rise as aquaculture expands further to meet the demand for seafood as the world's population continues to grow (Naylor et al., 2009).

Fishmeal is traditionally made from reduction fisheries consisting of small pelagic species such as menhaden, anchovy and sardine. Aquaculture is usually lauded for reducing harvest stresses on wild fish stocks, but the culture of carnivorous fishes such as salmonids and red drum now requires much fishmeal which might otherwise support wild fish production. Over 16 million tons of small pelagic fish are harvested yearly for conversion to fishmeal and fish oil (Tacon and Metian, 2008), and these stocks although sustainable are now considered fully exploited (Naylor et al. 2000). Aquaculture of carnivorous fish can use up to 5 kg of wild fish for every 1 kg of weight gain in the farmed stock (Naylor et al., 2000). However, much lower levels are used by herbivorous and omnivorous species. If the growth of aquaculture of various fish species continues as projected to meet the world's increasing demand for seafood, then other protein sources will need to be identified and incorporated into fish feeds to help replace fishmeal (Hardy and Tacon, 2002). Because of these concerns, identifying alternative protein sources and

This thesis follows the format and style of Aquaculture.

using underutilized resources in aquatic animal feeds are areas of needed research.

Many different plant sources have been researched and evaluated relative to fishmeal. Soybean meal, cottonseed meal, and other protein concentrates have all been extensively researched as alternative protein sources (Gatlin et al., 2007). Soybean meal has been shown to replace variable amounts of fishmeal without adversely affecting weight gain depending on the fish species. Some cultured species, including the red drum (Reigh and Ellis, 1992; McGoogan and Gatlin, 1997) and channel catfish (*Ictalurus punctatus*) (Mohsen and Lovell, 1990) can utilize relatively high levels of soybean meal (30 to 50% of diet) in place of fishmeal; whereas, other species such as the Atlantic salmon (*Salmo salar*) (Refstie et al., 1998) utilize much less (10 to 15% of diet). Higher levels of dietary soybean meal inclusion often result in reduced feed intake and may require amino acid supplementation that can be very expensive. Therefore, soybean meal is not an ideal protein source (Kikuchi, 1999). Animal proteins, such as seafood processing wastes, could potentially be employed as protein sources, or combined with soybean meal to provide a more complete protein feedstuff than soybean meal alone.

The amount of processing waste produced is another issue affecting the efficiency of aquaculture and seafood production worldwide. Over 143 million tons of seafood was produced in 2006, and that number increases every year to meet the demand of the world's growing population. The average waste from fish processing is roughly half the original harvest weight (Shih et al., 2003), and the processing of fish for fillets often leads to up to 66% of harvest weight being discarded in unused bones, heads and viscera (Knuckey et al., 2004). Waste products of shrimp processing typically are about 52% of total weight of the shrimp processed (Heu et al., 2003). Obviously this is a huge potential resource, as there is no shortage of seafood processing wastes. If the world's bycatch and seafood processing wastes were converted into fishmeal, it would nearly double the global fishmeal production, providing a large amount of material for aquatic feeds (Hardy et al., 2000).

Various terrestrial animal processing wastes such as poultry byproduct meal have been tested as an alternate protein sources in diets of various aquatic species. Poultry scraps processed into a meat and bone meal, and also freeze-dried scraps, have been tried with many different aquacultured species, including the red drum (Kureshy et al., 2000, Stone et al., 2000). For the most part, these processing wastes have proven effective, if slightly less effective than traditional fishmeal.

Feather meal, also made from poultry processing wastes, has also been used as a protein source in aquatic feeds. Feather meal has some amino acid deficiencies (Grazziotin et al., 2004), so it is often combined with corn gluten or blood meal. Feather meal also has been shown to be effective when partially replacing fishmeal (Hasan et al., 1997).

Bycatch from commercial fishing vessels has been evaluated as a protein source in red drum diets (Li et al., 2004). The bycatch of shrimp trawlers was found to effectively grow red drum, but the highly variable content, availability and quantity of bycatch makes it an unreliable source for widespread use in aquaculture. While bycatch meals have been shown to be very effective in growing cultured red drum (Moon and Gatlin, 1994), byproducts of seafood processing would be highly preferable for widespread use if it can be shown to be effective, due to their more consistent composition and supply.

Wastes from crab and finfish processing have proven effective in channel catfish feeds (Dean et al., 1992). Red drum has a higher protein requirement than channel catfish, however, and the cited study only used the protein from processing wastes at a 10% replacement level. So while that study showed there is potential for use of seafood processing wastes in the diet of channel catfish, it cannot be assumed that these feedstuffs will be effective in red drum diets.

Silage made from fish processing wastes has been incorporated in rainbow trout (*Oncorhynchus mykiss*) diets with good results (Stone et al., 1988). In that study, the processing waste silages had higher digestibility values than diets made from fishmeal, although growth rates of trout fed the silage diets were reduced. Studies using crustacean processing wastes have yielded similar results in rainbow trout (Ozogul, 1999). Trout were effectively grown when replacing a portion of the fishmeal in their diets with a crustacean byproduct, although amino acid supplementation was required for maximum growth.

Red drum is a species native to the Gulf of Mexico, and its use in aquaculture, both for stock enhancement and food production, is expanding rapidly. In the wild, larval red drum typically feed on zooplankton (Overstreet and Heard, 1978). As they grow into juveniles, they eat more benthic invertebrates, and when they are adults their diet consists primarily of fish and shrimp (Overstreet and Heard, 1978). Nutritional studies have shown that the red drum requires approximately 40% crude protein in its feed for ideal growth (Daniels and Robinson, 1986; Gatlin, 2002). Red drum also requires lipids with highly unsaturated fatty acids belonging to the linolenic acid (n-3) family to have healthy growth (Lochman and Gatlin, 1993). Studies have shown red drum is not harmed when fed high levels of soluble carbohydrate, but these carnivorous fish do process lipid more effectively than carbohydrate (Ellis and Reigh, 1991). Red drum also has been shown to digest animal proteins much more readily than plant proteins (Gaylord and Gatlin, 1996; Gatlin, 2002). Because of the red drum's relatively high protein demands, and its preference for animal proteins, the red drum is an appropriate species with which to evaluate seafood processing wastes.

This is a study of economic importance to Texas because aquaculture currently makes up the most rapidly growing segment of agriculture in Texas. This expansion cannot continue without new sources of high-quality ingredients that can be used in prepared feeds. Seafood processing wastes are logical candidates to be used as substitutes for fishmeal in the diets of various fish species.

Texas also is home to many seafood processing facilities, for both wild-caught and farm-raised aquatic species. This industry has also undergone expansion in recent years. The amount of wastes generated by these plants is of potential concern because of the great potential for environmental harm if the wastes are disposed of inappropriately. As a result, these facilities spend a great deal of money ensuring proper disposal of these wastes. Finding a more efficient use for these wastes would be a welcomed development.

Objectives

The ultimate goal of this study is to help alleviate harvest stresses on reduction fisheries by finding a high-quality alternate protein source. The specific objectives were to evaluate the nutritional value of wastes from black drum, channel catfish, and shrimp by blending them with soybean meal and subjecting them to dry extrusion.

Specific objectives were:

1) To determine nutrient and energy digestibility coefficients of the various processing wastes with red drum.

2) To determine the levels of fishmeal replacement each processing byproduct may achieve in diets of red drum based on a comparative feeding trial.

METHODS

To determine the most effective use of seafood processing wastes in red drum diets, two separate feeding trials were conducted at the Texas A&M Aquacultural Research and Teaching Facility (ARTF) located outside of College Station, TX. These trials were performed under well-established protocols approved by the University Laboratory Animal Care Committee of Texas A&M University. The chemical analyses were conducted at the Fish Nutrition Laboratory located on the Texas A&M central campus.

Experimental diets

Three different types of seafood processing wastes were obtained from commercial seafood processing facilities in Texas. First, visceral and skeletal scraps remaining after hand-filleting of black drum (*Pogonias cromis*) were obtained from Austin Seafood Products (Austin, TX); second, similar scraps remaining after machine-filleting of channel catfish (*Ictaluras punctatus*) were obtained from the Texas Catfish Cooperative (Markham, TX); and third, penaeid shrimp processing scraps consisting primarily of heads, hepatopancreatic tissue and exoskeletons were obtained from Lighthouse Seafoods (Palacios, TX). In each case, these scraps are typically discarded at great expense to the processor, and as a result reduce the efficiency and increase the operating cost of processing.

Each of the processing wastes was ground, homogenized and processed via dry extrusion in preparation for incorporation into experimental feeds. All processing took place at the Food Protein Research and Development Center (FPRDC) at Texas A&M.

After grinding, each processing waste was combined with dehulled, solvent-extracted soybean meal in a 40:60 (wet weight: dry weight) ratio.

Extrusion is often used when making aquatic feeds. The extrusion process only takes from 30 to 120 seconds and cooks ingredients into a highly digestible and pathogen-free product (Harper, 1981; Riaz and Lusas, 1996). The processing byproducts were extruded at 145-155 ºC, which released, as steam, much of the moisture contained in the scraps. The resulting products were then dried to 10% moisture or less to ensure long-term stability. The extruded products were then sent to the ARTF to be mixed with other ingredients in making the experimental feeds.

Complete diets were made from each of the three processing waste products. The protein sources were combined with a mineral premix, a vitamin premix, fish oil, dextrin and carboxymethyl cellulose, a commonly used binding agent. The dry ingredients for the diets were mixed in a V-mixer. Water and fish oil were then added to the dry ingredients and mixed in a Hobart mixer until homogeneous. Then the mixture was passed through a meat grinder with a 3-mm die on the end. The formed pellets were broken into an appropriate length by hand, and then dried by forced air at room temperature.

Feeding trial 1: Digestibility determinations

The Fish Nutrition Laboratory at Texas A&M has well-established protocols for determining feedstuff digestibility in various species including red drum (Gaylord and Gatlin, 1996). These protocols call for a non-digestible marker to be added to all diets. This trial used chromic oxide as the marker, added to all diets at 1% by weight. The chromic oxide levels in diets and collected fecal samples were used along with nutrient and energy levels to compute apparent digestibility coefficients.

All diets were formulated to contain 40% crude protein from either menhaden fishmeal (reference diet), or from one of the three treatment diets that incorporated shrimp byproduct, black drum byproduct, or catfish byproduct. All diets were also formulated to contain a total of 10% lipid from the ingredients and supplemental menhaden fish oil along with vitamin and mineral premixes to satisfy all known nutrient requirements of red drum. The formulation of the reference diet is presented in Table 1.

Table 1
Dry weight of ingredients in the reference diet (g/100 g)

Menhaden Meal	57.7
Experimental Protein	0
Menhaden Oil	3.5
Dextrin	20
Vitamin Premix	3
Mineral Premix	4
Carboxymethyl Cellulose	4
Chromic Oxide	1
Celufil	6.8
Crude protein %	40
Crude lipid %	10

Diets were fed to approximately 40 sub-adult red drum in each of six 1200-L fiberglass tanks linked together as a recirculating system at the ARTF. The water in the system was treated mechanically by a sand filter, and biologically using a biofilter filled with bacteria-promoting media. Water temperature was controlled at 26 ± 1 C by conditioning the ambient air. Airstones diffused air into the water, to keep dissolved oxygen levels as high as possible, and fluorescent lights controlled by timers provided a consistent 12 hour/12 hour light/dark cycle.

Each diet was assigned to a tank of fish and fed to apparent satiation twice daily for 2 weeks before fecal collection was initiated. Fecal collection was accomplished by manual expression of feces from each red drum in a tank approximately 5 to 6 hours after feeding, with the resulting composite samples from each tank dried and ground into a powder. Fecal samples were pooled by tank until approximately 2 to 3 g of fecal sample had been collected, after which diet and tank assignments were changed and another series of collections was made until three replicate samples were collected for each diet from each of the fish in different tanks.

Diet and fecal samples were analyzed for dry matter, organic matter, crude protein and crude lipid according to established methods (AOAC, 1990). Samples of the various diets and feces also were sent to the Texas A&M Shrimp Mariculture Laboratory in Port Aransas, TX for bomb calorimetry determination of energy content. Apparent digestibility coefficients (ADCs) were calculated for dry matter, organic matter, crude protein, crude lipid and energy based on established equations (Forster, 1999).

Feeding trial 2: Comparative feeding trial

Because digestibility coefficients do not give a total and complete evaluation of the nutritional value of experimental feedstuffs, a comparative feeding trial also was performed with juvenile red drum using the seafood processing waste products at several replacement levels for menhaden fishmeal.

All diets in this trial were formulated to contain 35% digestible protein based on values obtained in the digestibility trial. Replacement levels of 65%, 80%, or 95% of the protein from menhaden fishmeal were evaluated for each of the three byproducts except for the catfish byproduct which was included at only 65 and 80%. In addition, a reference diet using exclusively fishmeal as the protein feedstuff, as well as a diet in which half of the protein was provided by menhaden fishmeal and the other half by solvent-extracted dehulled soybean meal was included for comparison. The diets were supplemented with a vitamin premix, mineral premix, dextrin, fish oil, glycine (as an attractant), and carboxymethyl cellulose (Table 2).

Table 2
Composition of experimental diets (g dry weight of ingredient per 100 g)

Ingredient	Ref	50:50 Soy/ fish	Drum 65[1]	Drum 80	Drum 95	Shrimp 65	Shrimp 80	Shrimp 95	Cat 65	Cat 80
Menhaden Meal	58.32	29.73	19.29	10.3	1.3	19.3	10.29	1.3	19.3	10.3
Soybean Meal	0	36.9	0	0	0	0	0	0	0	0
Experimental Protein	0	0	52.89	65.08	77.28	53.58	65.95	78.3	54	66.45
Menhaden Oil	2.99	5.53	4.83	5.25	5.68	6.02	6.71	7.41	1.77	1.49
Dextrin	4.18	4.59	4.58	4.68	4.76	3.28	3.09	2.87	4.51	4.45
Vitamin Premix	3	3	3	3	3	3	3	3	3	3
Mineral Premix	4	4	4	4	4	4	4	4	4	4
Carboxymethyl Cellulose	2	2	2	2	2	2	2	2	2	2
Glycine	1	1	1	1	1	1	1	1	1	1
Celufil	24.51	13.25	8.41	4.69	.98	7.82	3.96	.12	10.48	7.25
Digestible protein%	35	35	35	35	35	35	35	35	35	35
Total lipid%	10	10	10	10	10	10	10	10	10	10

[1]Numbers in diet name represent replacement level of seafood processing waste in each diet.

For the comparative feeding trial, groups of 14 juvenile red drum (approximate size of 5 g each) were placed in 38-L glass aquaria as part of a recirculating system at the

ARTF. All environmental conditions were maintained in the same manner as described for the digestibility trial.

Efforts were taken to ensure that each group of fish weighed within 5% of each other at the initiation of the trial. Diet assignments were established in a completely random order. The fish were given a 1-week adjustment period before initiation of the trial. Fish assigned to each diet were fed the same fixed percentage of total body weight daily, initially at 6% and gradually reduced to 3% over the course of the experiment. Fish in each aquarium were collectively weighed each week. The feeding trial continued for 8 weeks, and measurements of weight gain, feed intake, feed efficiency ratio, percent protein retention and mortality rates were obtained. At the termination of the feeding trial, three fish from each tank were collected and prepared for proximate analysis (AOAC, 1990). Whole fish were weighed and then liver and intraperitoneal fat (IPF) tissues were dissected and weighed for computation of hepatosomatic index (HSI) and IPF ratio values.

Statistical analysis

The weight gain, feed efficiency and mortality data for red drum fed the various experimental diets were analyzed using one-way analysis of variance (ANOVA), with the significance level set at 5%. When significant dietary effects were identified, the statistical resolution of treatment means was assessed using Tukey's test (the Statistical Analysis System version 8.2, SAS Institute, Cary, NC, USA).

RESULTS

Digestibility trial

The diets used for the digestibility trial were formulated to contain 40% crude protein and 10% lipid, in accordance with optima established by previous studies with these nutrients for red drum (Williams and Robinson, 1988; Serrano et al., 1992). Table 3 shows that the formulated nutrient levels of the four digestibility trial diets were generally achieved based on proximate analysis.

Table 3
Proximate composition (%) of digestibility diets by percentage[1]

	Dry Matter	Ash	Lipid	Protein
Reference	94.7 (0.13)	15.7 (0.03)	7.8 (1.67)	41.8 (0.30)
Black Drum	92.2 (0.02)	14.4 (0.04)	6.7 (1.18)	44.7 (0.51)
Catfish	94.6 (0.03)	13.4 (0.06)	8.0 (0.82)	45.6 (0.69)
Shrimp	92.5 (0.05)	14.0 (0.08)	6.1 (0.12)	45.8 (0.89)

[1]Numbers in parenthesis give standard deviation from the mean for each main value.

Table 4 shows the apparent digestibility coefficient (ADC) values for dry matter, organic matter, crude protein, lipid and energy computed for red drum fed the various diets.

Table 4
ADC values of digestibility diets

	ADC dry matter	ADC organic matter	ADC lipid	ADC protein	ADC energy
Reference	69.4 [a]	75.2 [a]	57.5 [ab]	84.3 [b]	77.3 [a]
Black Drum	67.4 [a]	70.2 [c]	50.5 [ab]	85.5 [a]	76.1 [a]
Catfish	66.2 [a]	70.9 [b]	65.1 [a]	85.1 [a]	77.1 [a]
Shrimp	60.1 [a]	64.6 [d]	45.4 [b]	81.6 [c]	72.2 [b]
Pooled SE	3.13	0.02	3.50	0.13	0.67
ANOVA p-value	0.2554	0.0001	0.0099	0.0001	0.0021

Superscript letters give the results of Tukey's test. Values with the same letter are not significantly different from each other.

The reference diet containing menhaden fishmeal generally yielded the highest ADC values; however, differences in ADC values for the various diets were not of sufficient magnitude and consistency to register as statistically significant. None of the protein sources performed poorly enough to justify its exclusion from the comparative feeding trial. However, it was elected not to create a catfish 95% replacement diet due to lack of research space.

Comparative feeding trial

The formulation of the diets in the comparative feeding trial targeted 10% lipid and 35% digestible protein based on results of the digestibility trial. These levels were confirmed by proximate analysis.

Table 5 presents weight gain, feed efficiency ratio and other performance measures of the red drum in the comparative feeding trial.

Table 5
Performance measures of red drum fed diets with different kinds and amounts of byproduct meals in the comparative feeding trial

Diet designation	Percent weight gain	Survival (%)	Feed efficiency ratio[1]	Protein retention efficiency[2]	Energy retention efficiency[3]
Reference	645 [ab, 4]	96.4 [a]	0.77 [a]	35.4 [a]	33.9 [a]
50/50	692 [a]	85.7 [ab]	0.72 [ab]	25.3 [abc]	27.9 [ab]
Shrimp 65	542 [abc]	78.6 [ab]	0.66 [abc]	22.0 [bc]	23.9 [ab]
Shrimp 80	683 [a]	89.3 [a]	0.78 [a]	32.6 [a]	36.5 [a]
Shrimp 95	419 [cde]	73.8 [ab]	0.56 [bcd]	19.2 [cd]	20.5 [ab]
Drum 65	610 [ab]	90.5 [ab]	0.69 [ab]	29.7 [ab]	30.7 [a]
Drum 80	468 [bcd]	66.7 [ab]	0.61 [abc]	20.2 [bcd]	21.5 [ab]
Drum 95	261 [e]	78.6 [ab]	0.42[d]	11.3 [d]	12.6 [b]
Catfish 65	556 [abc]	71.4 [ab]	0.63 [abc]	19.1 [cd]	22.3 [ab]
Catfish 80	354 [de]	61.9 [b]	0.49 [cd]	12.6 [cd]	14.5 [b]
Pooled SE	37.25	6.05	2.94	2.07	3.05
ANOVA p-value	0.002	0.0096	0.0001	0.0001	0.0006

[1] ((final weight of fish + weight of deceased fish – initial weight of fish)/total feed fed) × 100
[2] (g protein gain/g protein fed) × 100.
[3](kcal gain/kcal fed) × 100.
[4]Superscript letters give the results of Tukey's test. Values with the same letter are not significantly different from each other.

Because I was attempting to achieve fish performance similar to that of the reference diet, I was looking for results that were not significantly different from those obtained with the reference diet. The performance measures showed clear separation between groups. Several groups performed as well as the reference group. In regards to weight-gain percentage, the 50/50 diet, the shrimp 65%, shrimp 80% and drum 65% all were not significantly different from the control group. All other diets performed significantly worse in percent weight gain. The reference diet had the highest survival percentage, but the fish fed the catfish 80% were the only group to perform worse at a statistically significant level. Fish fed the 50/50, shrimp 65%, shrimp 80%, drum 65%, drum 80%, and catfish 65% all had similar feed efficiency based on Tukey's test. Only the 50/50, shrimp 80% and drum 65% diets were grouped with the reference diet in all measures of performance.

Table 6 contains the hepatosomatic index values, intraperitoneal fat measurements, and proximate composition results of the sampled red drum after the conclusion of the trial.

Table 6
Condition indices and proximate composition of whole-body tissues of red drum fed the various diets in the growth trial

	Hepatosomatic index[1]	Intraperitoneal fat ratio[2]	Moisture percentage	Ash percentage	Lipid percentage	Protein percentage
Reference	1.4 [a, 3]	0.17 [a]	74.8 [a]	4.7 [a]	2.4 [a]	18.5 [a]
50/50	1.6 [a]	0.16 [a]	76.7 [a]	4.6 [a]	3.3 [a]	16.0 [a]
Shrimp 65	1.6 [a]	0.08 [a]	75.0 [a]	4.1 [a]	3.1 [a]	16.9 [a]
Shrimp 80	1.5 [a]	0.37 [a]	74.0 [a]	4.6 [a]	4.4 [a]	18.0 [a]
Shrimp 95	1.6 [a]	0.12 [a]	74.6 [a]	4.0 [a]	3.3 [a]	17.9 [a]
Drum 65	2.0 [a]	0.89 [a]	73.3 [a]	5.0 [a]	3.3 [a]	18.6 [a]
Drum 80	2.4 [a]	0.22 [a]	73.1 [a]	4.2 [a]	3.4 [a]	18.6 [a]
Drum 95	1.6 [a]	0.20 [a]	77.4 [a]	4.6 [a]	2.8 [a]	14.8 [a]
Catfish 65	1.9 [a]	0.19 [a]	76.2 [a]	3.5 [a]	3.9 [a]	15.8 [a]
Catfish 80	2.0 [a]	0.10 [a]	75.0 [a]	4.5 [a]	3.6 [a]	17.0 [a]
Pooled SE	.28	.22	1.37	.36	.42	.85
ANOVA p-value	.306	.3586	.3862	.2664	.2084	.0491

[1] (liver weight/weight of fish) × 100
[2] (weight of intraperitoneal fat/weight of fish) × 100
[3] Superscript letters give the results of Tukey's test. Values with the same letter are not significantly different from each other.

There were no significant differences found in the hepatosomatic indices or intraperitoneal fat. There was wide variability within treatments when it came to these two indices. Fish protein composition was almost completely within an acceptable range.

To more fully characterize the nutritional value of the experimental diets, amino acid profiles of each were analyzed using high pressure liquid chromatography (HPLC). The amino acid profiles of the diets can be seen in Table 7.

No large disparities in amino acid composition among diets were noticed. Diets associated with especially poor growth of red drum (Drum 95%, Catfish 65% and 80%) did not appear deficient in any specific amino acids when compared to the reference diet, or some of the other diets that supported better performance.

Table 7
Amino acid composition of the experimental diets (g/100g)

	Ref	50:50 Soy/fish	Drum 65	Drum 80	Drum 95	Shrimp 65	Shrimp 80	Shrimp 95	Cat 65	Cat 80
Aspartate	3.7	1.3	1.5	2.8	2.0	1.0	4.4	1.2	1.4	4.4
Glutamate	6.3	1.0	0.9	7.2	1.3	0.4	6.3	0.7	0.9	7.4
Asparagine	0	0	0	0	0	0	0	0.1	0	0
Serine	1.6	0.6	0.4	1.8	0.6	0.3	0.9	0.6	0.6	1.9
Glutamine	0.1	0	0.1	0	0	0.1	0	0.1	0.0	0
Histidine	0	0	0	0	0.6	0	0	0.7	0	0.2
Glycine	1.8	1.5	1.5	2.6	2.8	1.2	2.5	1.9	1.6	2.7
Threonine	1.6	0	0.7	1.6	0	0	2.8	0	0	1.9
Arginine	2.8	1.4	2.0	2.9	2.2	1.5	3.1	1.9	1.5	3.1
Taurine	0.3	0.1	0.3	0.3	0.2	0.1	0.3	0.1	0.1	0.2
Alanine	1.8	2.3	2.5	2.5	2.9	2.2	2.0	2.6	2.4	2.3
Tyrosine	1.7	1.2	1.6	1.8	1.9	1.0	1.9	1.5	1.1	2.0
Methionine	0.1	0.04	0	0.1	0	0	0.2	0	0.04	0.0
Valine	2.0	1.4	1.6	2.3	2.0	1.3	2.4	1.6	1.5	2.2
Phenylalanine	1.7	0.9	1.0	1.7	1.1	0.8	1.8	1.0	1.0	1.8
Isoleucine	1.5	1.1	1.2	1.7	1.3	1.0	1.7	1.2	1.2	1.7
Leucine	3.0	2.1	2.4	3.3	2.7	2.1	3.4	2.3	2.3	3.4
Ornithine	0.2	0.2	0.1	0.2	0.2	0.3	0.2	0.2	0.3	0.2
Lysine	2.63	2.10	1.18	3.12	2.96	1.94	3.12	2.04	2.30	3.08

DISCUSSION

In the digestibility trial, shrimp byproduct was proven to have lower digestibility than the other byproducts, but the Shrimp 80% diet supported the greatest growth of all diets in the comparative feeding trial. The lower digestibility is consistent with previous studies investigating shrimp processing byproduct. Shrimp processing waste has been found to have high levels of chitin, which is not an efficiently digested compound (Fanimo et al., 2000). Another trial also found lower apparent crude protein digestibility in red drum fed shrimp processing byproducts (Li et al., 2004). Non-protein nitrogen sources, such as glucosamine, contribute to the poor protein digestibility of feeds containing shrimp meal (Kobayashi et al., 2005). Chitin also has been linked to depressed absorption of dietary lipids at all replacement levels in tilapia (Shiau and Yu, 1999). Additionally, another trial found overall decreased growth in red drum fed shrimp processing byproduct meal (Whiteman and Gatlin, 2005). The discrepancy between results from my feeding trial and that of Whiteman and Gatlin (2005) is perhaps due to the soybean mixture used in my trial. Red drum require about 1.6-2.0% lysine in their feed (Brown et al., 1988), and shrimp processing meal is deficient in lysine (Fanimo et al., 2000). Soybean meal is a relatively rich source of lysine (Jarvis, 2004); Therefore, the mixture of protein sources used in my trial likely compensated for the limited lysine in the shrimp byproduct meal, as all my diets had a very high amount of lysine (Table 7).

Catfish byproduct proved to be less effective at growing red drum at all replacement levels. One previous study characterizing the nutritional value of catfish processing wastes indicated it could serve as a replacement protein source in both fish and pig diets (Lovell, 1980). However, based on the results of my growth trial with red drum, I would disagree with this assessment. Red drum fed the catfish byproduct diets at either level of substitution had generally reduced growth, survival percentage, and feed efficiency when compared to the reference diet.

Fish body composition did not vary greatly with the various dietary treatments evaluated in my comparative feeding trial. This agrees with results found in previous trials, where the primary protein source has very little effect on body composition, especially when protein and lipid levels were very similar among experimental diets (Moon and Gatlin, 1994; Whiteman and Gatlin, 2005) as they were in this trial.

Performance of red drum fed all three protein sources decreased as the fishmeal replacement level increased. With the exception of Shrimp 80%, all diets above 65% replacement of fishmeal had greatly reduced weight gain. One previous study found that once replacement of fishmeal was above 50%, growth of red drum was greatly reduced (Meilahn et al., 1996). While a serious decline in fish growth in my trial did not begin until a replacement percentage of higher than 50%, the trend was the same between the two trials.

The performance of red drum fed the shrimp and black drum diets at lower replacement levels suggest that those feedstuffs can be successfully incorporated as alternative protein sources in red drum diets, yet fishmeal is still needed to provide some of the protein. The incorporation of seafood processing wastes will allow the limited fishmeal resources to be extended further.

Further research is needed before the seafood processing wastes are widely incorporated in commercial feeds. In this trial, soybean meal was blended with the processing wastes to make up 60% of the blended protein mixture. Varying the amount of soybean meal relative to the seafood processing wastes may be worthy of further investigation. Red drum have been shown to grow well while receiving up to 90% of their dietary protein from soybean meal (McGoogan and Gatlin, 1997). It is also possible that incorporation of processing wastes at higher levels, or without soybean would be worth investigating.

Tilapia have been effectively grown on a diet in which all of its available protein came from a shrimp processing waste silage powder (Cavalheiro et al., 2007), and red drum have shown no ill effects from being fed a diet where up to 50% of the available protein was from shrimp bycatch (Li et al., 2004). My byproduct meals had 60% of their composition provided by soybean meal. Decreasing the ratio of soybean meal to byproduct should be investigated at some point to see if processing wastes can be incorporated at higher levels of replacement. However, increasing the percentage of wet mixture relative to soybean meal may reduce the friction needed for dry extrusion processing and thus should be monitored.

Also, mixing the processing byproduct with a dry protein source other than soybean should be investigated. There are many other protein sources that are used in aquaculture feeds, and it is possible the available amino acids of one of them better masks whatever deficiencies exist in the seafood processing byproducts. A great variety of sources can be considered to mix with the processing byproducts, from sources such as oilseeds, aquatic plants, algae, and terrestrial animals (El-Sayed, 1999). Investigations of total replacement of fishmeal by meat and bone meal, shrimp meal, and blood meal have proven to be less effective than fishmeal in growing tilapia (El-Sayed, 1998), but a mixture of one of these and the seafood processing byproduct could be beneficial. All of the materials listed in this section are cheaper than fishmeal, so there are also economic incentives to developing these feeds to the point of widespread implementation.

While the dry extrusion process does produce a highly palatable, pathogen-free product, there is some evidence that extruded product can lower the amount of amino acids effectively delivered to the absorptive portions of the small intestine (Orias et al., 2002). Measurements of extruded feed products have shown a decrease in amino acid concentration during the extrusion process, with some amino acids have losses of up to 10% through racemization and destruction from the heat of the process (Csapo et al., 2008). The protein that does make it into the intestine is generally readily absorbed, regardless of extrusion temperature (Robinson et al., 1985; Sorensen et al., 2002). Indeed, in trials testing the feasibility of dry extrusion, dry extruded experimental diets have repeatedly outperformed traditional diets when it comes to apparent digestibility of lipids and dry matter (Robinson et al., 1985; Cheng and Hardy, 2003). ADCs of protein may be depressed as a result of the extrusion process, though fish growth is often not adversely affected (Robinson et al., 1985; Cheng and Hardy, 2003). Measurements of the absorption of individual amino acids also have been found to be significantly depressed in a dry-extruded product when compared to a non-extruded product (Vens-Cappell, 1984; Opapeju et al., 2006). Several of these trials investigating extrusion were performed on rainbow trout, a fish that requires high dietary protein levels similar to the red drum. Despite the detrimental effect of dry extrusion noted above, it does appear to be the best option for converting waste proteins into a palatable fishmeal.

While it is apparent that dry extruded products are readily digested by red drum, the possible reduction in availability of some of the amino acids in the product may need to be investigated further. It is possible the dry extrusion reduced the bioavailability of some amino acids in the processing waste byproducts and thus caused decreased growth as seen in red drum fed several of the diets with higher inclusion of the processing byproducts. However, there were not adequate quantities of fecal samples collected in this study to measure amino acid availability. Experimenting with amino acid supplementation of these dry extruded diets should be attempted. Silage, another prominent way of preserving animal processing wastes, tends to be ineffectual for fish that require high protein diets. In one trial, a silage made from fish processing waste was fed to rainbow trout and compared to a dry fishmeal diet. While the silage did have higher apparent digestibility coefficients than the fishmeal, the fish fed silage were significantly smaller at the end of the trial (Stone et al., 1988). In another trial, rainbow trout fed a co-dried fish silage product performed significantly more poorly than trout fed a liquefied fish meal and a vacuum-dried fishmeal (Hardy et al., 1984). In that trial 25% replacement of fishmeal using the silage gave the best results among silage-fed groups. Replacement levels of 12.5% and 50% further decreased the final size of the silage-fed trout (Hardy et al., 1984). Feed conversion and protein efficiency were similarly depressed.

CONCLUSION

Because we are overfishing the world's oceans, it is vital we do whatever we can to lessen our yearly take of various fish species. An alternative source of high-quality seafood is aquaculture. Using widely available seafood processing wastes to replace at least some of the fishmeal in animal feed could be a huge benefit, as it can lower operating costs of aquaculture facilities and seafood processing facilities, and lower harvesting stresses on reduction fisheries.

Further potential research in this field that would be beneficial includes testing the byproduct meals, especially catfish, below 50% replacement in high protein diets for aquacultured fish. If the catfish byproduct proves effective at even 10% replacement, that is still a huge amount of fishmeal that is not being added to aquaculture diets every year.

Based on the results of these experiments, it is recommended that shrimp and drum byproduct meals be included at lower levels of replacement into the diet of red drum. Using the catfish byproduct as a protein source for red drum is not recommended until a replacement level that allows for sufficient growth is determined.

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