

# Optimization of growout diets for red drum, *Sciaenops ocellatus*

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## Abstract

Because of the high costs associated with feed inputs, as well as increased concern about waste production on fish farms, there is considerable interest in developing growout diets which are both cost effective and low polluting. In two 12-week growth trials, the response of subadult red drum, *Sciaenops ocellatus*, fed either a diet of 440 or 360 g protein kg<sup>-1</sup> diet (44% or 36%) with varying E:P ratios were tested. In the first experiment, five diets containing 440 g protein kg<sup>-1</sup> diet and one diet containing 360 g protein kg<sup>-1</sup> diet (reference) were offered to red drum (mean initial weight of 186 g). The five test diets contained 83, 103, 123, 143, and 163 g lipid kg<sup>-1</sup> diet, resulting in E:P ratios ranging from 34.3 to 38.9 kJ g protein<sup>-1</sup>. In experiment 2, five diets providing 360 g protein kg<sup>-1</sup> diet and one diet containing 440 g protein kg<sup>-1</sup> diet (reference) were offered to red drum (mean initial weight of 145 g). Dietary lipid levels included 83, 123, and 163 g lipid kg<sup>-1</sup> diet, and dietary carbohydrate was diluted with 10% and 20% non-nutritive bulk filler in two of the diets to result in E:P ratios ranging from 34.5 to 46.7 kJ g protein<sup>-1</sup>. In experiment 1, no significant differences in mean final weight, mean weight gain, feed efficiency, protein conversion efficiency or hepatosomatic index were observed between the five test diets providing 440 g protein kg<sup>-1</sup> diet. Intraperitoneal fat generally increased with increasing dietary lipid. The results of experiment 2 indicate that amongst the test diets with 360 g protein kg<sup>-1</sup> diet, mean final weight, mean weight gain, feed efficiency, protein conversion efficiency and hepatosomatic index were not significantly different. Intraperitoneal fat significantly increased with increasing dietary lipid. In both experiments, fish offered diets with 440 g protein kg<sup>-1</sup> diet produced significantly higher growth and FE values as compared to fish receiving diets containing 360 g protein kg<sup>-1</sup> diet. This study indicated that subadult

red drum are tolerant of shifts in E:P ratios and utilize a wide range of dietary lipid and carbohydrate without compromising growth.

**KEY WORDS:** growout, nutrition, protein, red drum, *Sciaenops ocellatus*

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## Introduction

The manipulation of diet formulations with respect to ingredient costs, nutrient profile and digestibility, as well as the adaptation of feeding regimes designed for site-specific farming conditions can result in significant reductions in pollution loading and cost (Cho *et al.* 1994). The red drum, *Sciaenops ocellatus*, is a commercially important species cultured worldwide, which could benefit from the use of improved feeds and feed management strategies. Feed formulations used in current production diets have benefited from increased research with respect to the nutritional requirements for this species. Dietary protein requirements (Lin & Arnold 1983; Daniels & Robinson 1986; Serrano *et al.* 1992; McGoogan & Gatlin 1998), essential amino acid requirements (Brown *et al.* 1988; Moon & Gatlin 1989; Moon & Gatlin 1991; Boren & Gatlin 1995), energy requirements (Daniels & Robinson 1986), and the utilization of various forms of energy, such as carbohydrates (Ellis & Reigh 1991; Serrano *et al.* 1992) and lipids (Williams & Robinson 1988; Ellis & Reigh 1991; Serrano *et al.* 1992; Craig & Gatlin 1995) have been identified. Further

nutritional studies include essential fatty acid (EFA) profiles and requirements (Lochmann & Gatlin 1993a, b; Villarreal *et al.* 1994) and vitamin and mineral requirements (Davis & Robinson 1987; Gatlin *et al.* 1991; Craig & Gatlin 1996).

The availability of previous literature has aided considerably in creating cost-effective feeds. However, these studies have primarily been conducted with red drum fingerlings (initial weight; 0.4–13.0 g fish<sup>-1</sup>); whereas farm managers incur most of their feed costs during the growout stage, when fish are larger. During this culture period, red drum are initially stocked as fingerlings (40–60 g) and harvested as a market-sized fish (454–1360 g). Use of suboptimal feeds at this stage not only increases costs to the farmer, but also increases nutrient build-up in the system (Jirsa *et al.* 1997). Thus, cost of growout feeds and the input of excess nutrients could possibly be reduced by manipulating the nutrient content of diets for this stage of production.

In accordance with the nutritional requirements of a given species, manipulation of feed ingredients assists in the development of a diet that optimizes digestion, absorption and utilization of nutrients while reducing waste material. Dietary protein is most often the first nutrient in a diet to be manipulated. As an expensive component of the diet and major source of nitrogen, protein should ideally be used for tissue deposition. However, fish also efficiently use protein as a source of energy (Lovell 1989). The inclusion of excess dietary protein, improper energy to protein (E:P) ratios and imbalanced protein sources in terms of essential amino acids, can result in excess nitrogenous waste, as well as decreased feed performance and overall cost inefficiency.

In order to minimize the utilization of protein as an energy source, other sources of digestible energy must be provided. Carbohydrates are typically less expensive forms of dietary energy for man and domestic animals, but the extent of their utilization by fish varies considerably (Wilson 1994). Other energy sources include lipids, which are a highly available source of energy and are required to meet the EFA requirement of a species (Watanabe 1982). Protein may be spared as lipids and carbohydrates are catabolized as energy, allowing protein to be used for tissue development. Several studies have evaluated variations in lipid levels in diets for red drum juveniles. Williams & Robinson (1988) reported an optimum dietary lipid level of 7–11%. Ellis & Reigh (1991) had similar results when 10% lipid was included in the diet, and determined that dietary lipid energy was utilized more efficiently than carbohydrate energy.

Inclusion of increased levels of digestible sources of lipid and carbohydrate typically increases total available energy content of the diet and could minimize the use of protein as

an energy source. However, an excess of energy, relative to the protein content of the diet, could influence feed intake. As with other animals, the level of feed consumption by fish is generally thought to be related to a specific energy requirement (Kaushik & Luquet 1984); consequently, offering feed with higher energy content could result in decreased consumption. As dietary excesses or deficiencies of available energy have been related to reduce growth rate (Lovell 1989), the optimization of energy content and E:P ratio is necessary in order to attain desirable growth, and may also reduce waste output and overall feed costs.

To help meet the various needs of production facilities, a range of feed types must be available to the farmer. Ultimately feeds must be formulated with various protein and energy levels to fulfil site-specific needs in terms of a facility's microeconomy. Hence, the objective of this study was to evaluate the effects of variations in E:P ratio for two practical diets, containing either 440 or 360 g protein kg<sup>-1</sup> diet, offered to subadult red drum.

## Materials and methods

### Experimental design

Two 12-week growth trials were undertaken in order to evaluate the growth of red drum fed high and low protein diets, 440 and 360 g protein kg<sup>-1</sup> diet (44% and 36%), respectively, with manipulations in energy levels. In both studies, 18 semisquare polyethylene tanks, designed to hold 570 L of water were utilized as part of a semiclosed recirculating system. The system makeup water was exchanged at a rate of approximately 19 L min<sup>-1</sup> throughout the experiments. Water was filtered through a 960 L rectangular fiberglass biological filter consisting of two trickling towers and a submerged plastic substrate filter. A 1-hp pump was used to circulate water through a sand filter and the culture tanks twice per hour. Temperature was maintained via two 2.0 kW submersible heaters. A 12 h light, 12 h dark photoperiod was established using fluorescent lamps with timers.

Tanks were initially stocked with an excess of size-sorted fish which were allowed to acclimate to the culture system for 7 days. During the initial stocking period for both experiments, six fish were sacrificed and frozen for subsequent proximate analysis. Following this period of acclimation, tanks were cleaned and restocked to an equivalent biomass. In experiment 1, ten fish per tank (mean initial weight 186 g) were stocked, where as in experiment 2, eight fish per tank (mean initial weight 145 g) were stocked. Red drum used in

both experiments were spawned and reared at the University of Texas Marine Science Institute Fisheries and Mariculture Laboratory. Water quality was evaluated biweekly for pH, and total ammonia nitrogen (TAN) and nitrite-nitrogen ( $\text{NO}_2$ ), using methods described by Spotte (1979). Temperature, dissolved oxygen (DO) and salinity were monitored daily. Water quality during experiment 1 showed the following variation (mean  $\pm$  SD): pH,  $7.77 \pm 0.09$ ; TAN,  $0.20 \pm 0.08 \text{ mg L}^{-1}$ ;  $\text{NO}_2$ ,  $0.11 \pm 0.11 \text{ mg L}^{-1}$ , temperature,  $28.54 \pm 1.16 \text{ }^\circ\text{C}$ ; DO,  $5.56 \pm 0.49 \text{ mg L}^{-1}$ ; and salinity,  $32.3 \pm 2.1$  ppt. During experiment 2, water quality measurements were as follows (mean  $\pm$  SD): pH,  $7.70 \pm 0.15$ ; TAN,  $0.02 \pm 0.09 \text{ mg L}^{-1}$ ;  $\text{NO}_2$ ,  $0.15 \pm 0.16 \text{ mg L}^{-1}$ ; temperature,  $27.95 \pm 1.49 \text{ }^\circ\text{C}$ ; DO,  $5.98 \pm 0.54 \text{ mg L}^{-1}$ ; and salinity,  $25.3 \pm 4.8$  ppt.

For each experiment, six experimental diets were prepared and randomly assigned to the 18 tanks, yielding three replicates per diet. Following initial stocking, specimens were weighed every 14 days during which tanks were cleaned and fish were dipped in freshwater. Feed was offered twice daily (08.00 and 17.00 hours) throughout the experiments and was withheld on weighing days. After weighing, feed rates were adjusted according to weight gain (final wet weight – initial wet weight), feed efficiency (FE; wet weight gain  $\times$  100/dry feed fed) and apparent consumption.

#### *Diet formulations*

Dry weight composition of the 12 practical diets are presented in Table 1. Experiment 1 included a reference diet (R36) providing 360 g protein  $\text{kg}^{-1}$  diet, and five diets supplying 440 g protein  $\text{kg}^{-1}$  diet. Dietary energy was increased with the addition of menhaden fish oil. As a result, total lipid levels of 83, 103, 123, 143 and 163 g lipid  $\text{kg}^{-1}$  diet were established. In experiment 2, a reference diet (R44) with 440 g protein  $\text{kg}^{-1}$  diet and five diets with 360 g protein  $\text{kg}^{-1}$  diet were offered. Dietary gross energy levels were manipulated from that of a basal diet (diet 8) by replacement of the carbohydrate source with 20% and 10% non-nutritive bulk filler and increasing lipid levels with the addition of menhaden fish oil. Lipid levels were evaluated at 83, 123 and 163 g lipid  $\text{kg}^{-1}$  diet.

Feed was prepared by first homogenizing ingredients in a food mixer (Hobart Corp., Troy, OH, USA). Boiling water was added to obtain a consistency appropriate for pelleting. The mash was then cold extruded through a meat grinder (4 mm die), and dried for 5 h at  $40 \text{ }^\circ\text{C}$  in a forced-air convection oven. Extruded pellets were then air-cooled overnight in order to obtain an approximate moisture

content of 8–10%. Feed was then crumbled to an appropriate size (approximately 6 mm). Protein content was confirmed using the micro-Kjeldahl method (Ma & Zuazago 1942) and percent dry matter of the feed was determined by drying the sample to a constant weight at  $90 \text{ }^\circ\text{C}$ .

#### *Sample collection and analyses*

Upon termination of each growth trial, three randomly selected fish from each tank were sacrificed and weighed. The liver and intraperitoneal fat from each sample were removed and weighed in order to determine hepatosomatic index (HSI; wet liver weight  $\times$  100/wet body weight) and intraperitoneal fat ratio (IPF; wet weight of fat  $\times$  100/wet body weight). The liver and intraperitoneal fat were then homogenized with the remainder of the dissected fish. After homogenizing, a sample was taken for whole body dry matter and protein analysis. Dry matter was determined in duplicate by drying the sample to a constant weight at  $90 \text{ }^\circ\text{C}$ . Whole body protein was determined in triplicate. Protein conversion efficiency (PCE; protein gain  $\times$  100/protein fed) was calculated upon termination of the experiment.

#### *Statistical analyses*

The collected data was analysed using one-way analysis of variance (ANOVA) to determine significant differences ( $P < 0.05$ ) among treatment means. Student–Neuman–Keuls multiple comparison test was used to separate significant differences between treatment means (Steel & Torrie 1980). All statistical analyses were conducted using the Statistical Analysis System (v6.12, Cary, NC, USA).

## **Results**

### *Experiment 1*

Red drum adapted to the experimental system well, and no disease or water quality problems were noted during either study. The response of red drum to the test diets in experiment 1 is shown in Table 2. Individuals offered any variation of the diet providing 440 g protein  $\text{kg}^{-1}$  diet showed significantly higher mean final weight, mean weight gain, and FE than those offered the reference diet with 360 g protein  $\text{kg}^{-1}$  diet. However, no significant differences in mean final weight, mean weight gain, or FE were observed for those offered the five test diets. Mean weight gain (% weight gain) among fish fed the five test diets ranged from 296 to 330 g (134–175%).

**Table 1** Diet formulations (g kg<sup>-1</sup> dry weight)

Ingredient	Experiment 1					Experiment 2						
	Ref36	1	2	3	4	5	Ref44	6	7	8	9	10
Fish meal <sup>1</sup>	245	300	300	300	300	300	300	245	245	245	245	245
Soy protein isolate <sup>2</sup>	82	100	100	100	100	100	100	82	82	82	82	82
Soybean meal <sup>3</sup>	203	248	248	248	248	248	248	203	203	203	203	203
Menhaden fish oil <sup>4</sup>	40	40	60	80	100	120	40	47	47	47	87	127
Wheat gluten <sup>5</sup>	33	40	40	40	40	40	40	33	33	33	33	33
Wheat starch <sup>5</sup>	310	176	156	136	116	96	176	103	203	303	263	223
Nutribinder <sup>6</sup>	41	50	50	50	50	50	50	41	41	41	41	41
Trace mineral premix <sup>7</sup>	5	5	5	5	5	5	5	5	5	5	5	5
Vitamin premix <sup>8</sup>	30	30	30	30	30	30	30	30	30	30	30	30
Vitamin C 250 (mg kg <sup>-1</sup> ) <sup>9</sup>	1	1	1	1	1	1	1	1	1	1	1	1
KPO4 <sup>10</sup>	5	5	5	5	5	5	5	5	5	5	5	5
Soy lecithin <sup>11</sup>	5	5	5	5	5	5	5	5	5	5	5	5
Filler-cellulose <sup>12</sup>	–	–	–	–	–	–	–	200	100	–	–	–
Formulated to contain												
Protein (g kg <sup>-1</sup> )	360	440	440	440	440	440	440	360	360	360	360	360
Total lipid (g kg <sup>-1</sup> )	76	83	103	123	143	163	83	83	83	83	123	163
DE (kJ g <sup>-1</sup> ) <sup>13</sup>	14.6	15.1	15.6	16.1	16.6	17.1	15.1	12.4	13.6	14.8	15.8	16.8
E:P (kJ g protein <sup>-1</sup> )	40.7	34.3	35.5	36.6	37.8	38.9	34.3	34.4	37.8	41.1	43.9	46.7

<sup>1</sup> Menhaden Fish Meal, Special Select<sup>TM</sup>, Zapata Protein USA Inc., Mandeville, LA, USA.

<sup>2</sup> Nourish 3000<sup>®</sup>, ProteinTechnologies International, St Louis, MO, USA.

<sup>3</sup> Solvent extracted, Producers Coop, Bryan, TX, USA.

<sup>4</sup> Omega Protein, Reedville, VA, USA.

<sup>5</sup> United States Biochemical Corporation, Cleveland, OH, USA.

<sup>6</sup> Industrial Grain Products Inc., Lubbock, TX, USA.

<sup>7</sup> g(100 g)<sup>-1</sup> 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.

<sup>8</sup> g kg<sup>-1</sup> premix: thiamin HCL 0.5, riboflavin 3.0, pyridoxine HCL 1.0, DI Ca-Pantothenate 5.0, nicotinic acid 5, biotin 0.05, folic acid 0.18, vitamin B12 0.002, choline chloride 100.0, inositol 5.0, menadione 2.0, vitamin A acetate (20 000 IU g<sup>-1</sup>) 5.0, vitamin D3 (400 000 IU g<sup>-1</sup>) 0.002, dL- $\alpha$ -tocopherol acetate (250 IU g<sup>-1</sup>) 8.0,  $\alpha$ -cellulose 865.266.

<sup>9</sup> Rovimix<sup>®</sup>, Stay C<sup>®</sup> (L-Ascorbyl-2-Polyphosphate 25% Active C), Roche Vitamins Inc., Parsippany, NJ, USA.

<sup>10</sup> Spectrum Chemical Mfg. Corp., Gardendale, CA, USA.

<sup>11</sup> Aqualipid 95, Central Soya Chemurgy Division, Fort Wayne, IN, USA.

<sup>12</sup> ICN Biochemicals, Aurora, OH, USA.

<sup>13</sup> Calculated based on digestible energy (DE) values reported by Gaylord & Gatlin (1996) and Davis (University of Texas, unpublished data) for red drum, and DE values summarized for catfish (Lovell 1989).

**Table 2** Response of red drum in experiment 1 (mean initial weight 186 g) to test diets over a 12-week growth trial<sup>1</sup>

Diet	Final weight (g)	Weight gain (g)	Survival (%)	FE <sup>2</sup> (%)	PCE <sup>3</sup> (%)
Ref36	440.4 <sup>b</sup>	252.5 <sup>b</sup>	96.7 <sup>a</sup>	55.7 <sup>b</sup>	28.4 <sup>a</sup>
1	500.8 <sup>a</sup>	317.4 <sup>a</sup>	100.0 <sup>a</sup>	70.0 <sup>a</sup>	29.3 <sup>a</sup>
2	481.8 <sup>a</sup>	296.2 <sup>a</sup>	100.0 <sup>a</sup>	65.3 <sup>a</sup>	27.8 <sup>a</sup>
3	492.4 <sup>a</sup>	307.6 <sup>a</sup>	100.0 <sup>a</sup>	67.8 <sup>a</sup>	30.7 <sup>a</sup>
4	517.4 <sup>a</sup>	329.6 <sup>a</sup>	100.0 <sup>a</sup>	72.6 <sup>a</sup>	30.0 <sup>a</sup>
5	505.3 <sup>a</sup>	318.9 <sup>a</sup>	100.0 <sup>a</sup>	70.4 <sup>a</sup>	32.2 <sup>a</sup>
PSE <sup>4</sup>	11.4	11.4	1.4	3.2	2.6

<sup>1</sup> Means of three replicates. Numbers within the same column with different superscripts are significantly different ( $P < 0.05$ ).

<sup>2</sup> Feed efficiency (FE) = (weight gain  $\times$  100/feed fed).

<sup>3</sup> Protein conversion efficiency (PCE) = (protein gain  $\times$  100/protein fed).

<sup>4</sup> Pooled standard error.

At the conclusion of experiment 1, no significant differences were observed for fish offered any of the test diets in whole body dry matter, percent protein and HSI (Table 3). A general trend of increasing IPF ratio with increasing lipid in the diet was observed; however, significant differences (as indicated by ANOVA) were not detected by the means separation test.

### Experiment 2

Growth, FE, percent survival, and PCE of fish offered the test diets in experiment 2 are presented in Table 4. Red drum offered the five test diets containing 360 g protein kg<sup>-1</sup> diet resulted in weight gain (% weight gain) ranging from 274 to 311 g (188–244%) with no significant differences in mean final

**Table 3** Whole body analysis, intraperitoneal fat ratio (IPF) and hepatosomatic index (HSI) of red drum fed test diets during experiment 1<sup>1</sup>

Diet	Whole body (g kg <sup>-1</sup> )			
	Dry matter	Protein	IPF <sup>2</sup>	HSI <sup>3</sup>
Ref36	298 <sup>a</sup>	608 <sup>a</sup>	1.0 <sup>a</sup>	1.6 <sup>a</sup>
1	287 <sup>a</sup>	629 <sup>a</sup>	0.8 <sup>a</sup>	1.4 <sup>a</sup>
2	290 <sup>a</sup>	630 <sup>a</sup>	1.2 <sup>a</sup>	1.5 <sup>a</sup>
3	298 <sup>a</sup>	626 <sup>a</sup>	1.5 <sup>a</sup>	1.7 <sup>a</sup>
4	298 <sup>a</sup>	612 <sup>a</sup>	1.8 <sup>a</sup>	1.7 <sup>a</sup>
5	311 <sup>a</sup>	616 <sup>a</sup>	1.8 <sup>a</sup>	1.6 <sup>a</sup>
PSE <sup>4</sup>	8	24	0.2	0.1

<sup>1</sup> Means of three replicates. Numbers within the same column with different superscripts are significantly different ( $P < 0.05$ ).

<sup>2</sup> Intraperitoneal fat (IPF) = (wet weight of fat  $\times$  100/wet body weight).

<sup>3</sup> Hepatosomatic index (HSI) = (wet liver weight  $\times$  100/wet body weight).

<sup>4</sup> Pooled standard error.

weight, mean weight gain or FE. Protein conversion efficiency was not significantly different for fish fed any of the diets.

Upon dissection and whole body analysis, no significant differences in percent dry matter, percent protein, or HSI were observed in red drum offered the test diets (Table 5). However, IPF ratios were significantly influenced by dietary lipid. Red drum offered diet ten yielded a significantly higher IPF ratio (3.6) in comparison to all other diets. Fish offered diet 9 showed a significantly higher IPF ratio than those offered diet 6, but not significantly different from the reference diet and diets 7 and 8.

## Discussion

Manipulation of dietary protein, carbohydrates and lipid levels have been shown to have significant effects on growth of juvenile red drum. For example, increased levels of dietary protein have been shown to improve growth and FE in red drum juveniles (Daniels & Robinson 1986; Serrano *et al.* 1992; Jirsa *et al.* 1997). Similarly, a recent study with subadult red drum (mean initial weight 50 g) reported that growth rates increased as dietary protein was increased from 320 to 440 g kg<sup>-1</sup> diet (Thoman *et al.* 1999). It was concluded that although a diet containing 440 g protein kg<sup>-1</sup> produced the best results, growth resulting from a diet with 360 g protein kg<sup>-1</sup> diet may be acceptable under some conditions. However, if diets are to support maximum growth rates and feed utilization, manipulation of E:P ratios should be evaluated.

For the current study, diets containing either 440 or 360 g protein kg<sup>-1</sup> diet with varying E:P ratios were evalu-

**Table 4** Response of red drum in experiment 2 (mean initial weight 145 g) to test diets over a 12 week growth trial<sup>1</sup>

Diet	Final weight (g)	Weight gain (g)	Survival (%)	FE <sup>2</sup> (%)	PCE <sup>3</sup> (%)
Ref44	591.2 <sup>a</sup>	447.4 <sup>a</sup>	100.0 <sup>a</sup>	67.0 <sup>a</sup>	30.4 <sup>a</sup>
6	531.6 <sup>b</sup>	386.9 <sup>b</sup>	100.0 <sup>a</sup>	62.0 <sup>b</sup>	30.9 <sup>a</sup>
7	519.3 <sup>b</sup>	374.6 <sup>b</sup>	100.0 <sup>a</sup>	61.2 <sup>b</sup>	30.2 <sup>a</sup>
8	485.2 <sup>b</sup>	339.6 <sup>b</sup>	100.0 <sup>a</sup>	56.8 <sup>b</sup>	26.9 <sup>a</sup>
9	516.0 <sup>b</sup>	369.4 <sup>b</sup>	95.8 <sup>a</sup>	60.0 <sup>b</sup>	25.5 <sup>a</sup>
10	494.7 <sup>b</sup>	349.0 <sup>b</sup>	100.0 <sup>a</sup>	58.9 <sup>b</sup>	27.1 <sup>a</sup>
PSE <sup>4</sup>	11.6	10.8	1.7	0.87	1.87

<sup>1</sup> Means of three replicates. Numbers within the same column with different superscripts are significantly different ( $P < 0.05$ ).

<sup>2</sup> Feed efficiency (FE) = (weight gain  $\times$  100/feed fed).

<sup>3</sup> Protein conversion efficiency (PCE) = (protein gain  $\times$  100/protein fed).

<sup>4</sup> Pooled standard error.

ated. In both experiments, growth in terms of mean final weight and mean weight gain was significantly higher for fish receiving diets providing 440 g protein kg<sup>-1</sup> diet as compared to diets containing 360 g protein kg diet thus, confirming the results of Thoman *et al.* (1999). However, manipulation of E:P ratios of the five test diets in either experiment did not result in significant shifts in growth within each protein level. In experiment 1, variations in dietary energy levels and subsequent E:P ratios were achieved through increases in total dietary lipid content from 83 to 163 g lipid kg<sup>-1</sup> diet, resulting in E:P ratios of 34.3–38.9 kJ g protein<sup>-1</sup>. No significant differences in mean final weight, mean weight gain, and FE were observed for fish offered the test diets. A similar trend was observed in experiment 2, in which dietary E:P ratios of the test diets increased from 34.5 to 46.7 kJ g protein<sup>-1</sup> as a result of either increasing lipid levels

**Table 5** Whole body analysis, intraperitoneal fat ratio (IPF) and hepatosomatic index (HSI) of red drum fed test diets during experiment 2<sup>1</sup>

Diet	Whole body (g kg <sup>-1</sup> )			
	Dry matter	Protein	IPF <sup>2</sup>	HSI <sup>3</sup>
Ref44	312 <sup>a</sup>	627 <sup>a</sup>	1.8 <sup>bc</sup>	1.5 <sup>a</sup>
6	305 <sup>a</sup>	604 <sup>a</sup>	1.6 <sup>c</sup>	1.4 <sup>a</sup>
7	300 <sup>a</sup>	613 <sup>a</sup>	1.7 <sup>bc</sup>	1.4 <sup>a</sup>
8	295 <sup>a</sup>	607 <sup>a</sup>	1.8 <sup>bc</sup>	1.5 <sup>a</sup>
9	286 <sup>a</sup>	566 <sup>a</sup>	2.4 <sup>b</sup>	1.7 <sup>a</sup>
10	294 <sup>a</sup>	589 <sup>a</sup>	3.6 <sup>a</sup>	1.5 <sup>a</sup>
PSE <sup>4</sup>	7	18	0.2	0.1

<sup>1</sup> Means of three replicates. Numbers within the same column with different superscripts are significantly different ( $P < 0.05$ ).

<sup>2</sup> Intraperitoneal fat (IPF) = (wet weight of fat  $\times$  100/wet body weight).

<sup>3</sup> Hepatosomatic index (HSI) = (wet liver weight  $\times$  100/wet body weight).

<sup>4</sup> Pooled standard error.

from 83 to 163 g lipid kg<sup>-1</sup> diet, or the addition of 10–20% inert bulk filler. Variations in E:P ratios did not significantly affect mean final weight, mean weight gain, or FE among the test diets.

The addition of filler to the test diets in experiment 2 was intended to lower the available dietary energy levels and result in a more favorable E:P ratio. However, significant differences were not observed among fish offered the various test diets. This may have been partially because of shifts in the digestible energy content of the carbohydrate sources in the diet. Digestible energy available to channel catfish has been shown to decrease as carbohydrate levels in diets increased from 30% to 60% (Lovell 1989). This would suggest that addition of bulk filler may not have substantially changed the digestible energy of the diets. In the absence of significant differences among the diets containing 360 g protein kg<sup>-1</sup> diet, the addition of 20% inert filler may be utilized without compromising growth, FE or PCE. Hence, less expensive low digestible carbohydrates could be utilized in low protein (260 g kg<sup>-1</sup> diet) production diets without reducing growth.

Growth results of experiments 1 and 2 differ from previous studies with red drum juveniles. Depressed growth, FE and PCE values have been correlated with increasing dietary energy content (Daniels & Robinson 1986; Williams & Robinson 1988; Ellis & Reigh 1991). It was suggested that higher energy diets reduced consumption, and therefore, decreased growth. Results of the present study indicate that growth was not affected by dietary energy level, and that feed intake of subadult red drum may not be related to energy content of the diet. Similarly, in a satiation feeding experiment, Thoman *et al.* (1999) reported no significant differences in consumption by subadult red drum (mean initial weight 50 g) offered diets containing various levels of protein and energy. Hence, it would appear that larger red drum may eat to a fill, regardless of energy content.

The evaluation of growth performance was also measured through levels of lipid deposition and whole body analysis. For experiment 1, analysis of variance indicated significant differences in IPF ratio, however, this was not observed by the Student–Newman–Keuls test. In experiment 2 a general increase in IPF ratio with increased dietary lipid was observed. Individuals offered diet 10 yielded significantly higher IPF ratio (3.57) than all other test diets. Similar results were obtained by Serrano *et al.* (1992), in which red drum fed diets with higher lipid levels showed increased IPF ratio. Red drum fed diet 9 had significantly higher IPF ratios than those fed diet 6, but not significantly different from all other test diets. The addition of 20% inert filler and subsequent

decrease in E:P ratio and digestible carbohydrates in diet 6 resulted in the least amount of fat deposition in fish offered this diet. This may indicate that an excess of energy in the other test diets resulting in increased fat deposition. Since the presence of excess fat in the body cavity of fish may result in decreased value during processing (reduced dress-out percentages and shelf-life), excess energy often represents reduced cost efficiency with respect to feed ingredients as well as increased costs incurred during processing.

The proximate analysis of fish, and size of the liver may change with shifts in energy levels. In both experiments whole body analysis showed that percent dry matter, percent protein and HSI were not significantly different. These results differ from those observed by Daniels & Robinson (1986) and Serrano *et al.* (1992) in which increases in dietary lipid and carbohydrate resulted in decreased whole body protein and increased HSI. Differences seen in the present study are most likely because of the larger size individuals used in this study and their ability to tolerate shifts in E:P ratios. In addition, decreased levels of dietary energy (reduced E:P ratios) have resulted in protein being used as an energy source rather than tissue development, resulting in a significant change in PCE (Watanabe 1977, 1982; Ellis & Reigh 1991; Serrano *et al.* 1992). In experiments 1 and 2, no significant differences in PCE were observed, indicating that adequate energy was available, as protein deposition was not significantly altered.

## Conclusion

The results of the current study indicate that subadult red drum are able to utilize a wider range of carbohydrates and lipids, which varies from red drum juveniles whose tolerance to these dietary components appear more rigid. Subadult red drum performed best, in terms of growth and FE, when offered a diet with 440 g crude protein kg<sup>-1</sup> diet and the inclusion of 80–120 g dietary lipid kg<sup>-1</sup> diet. However, in situations where growth rate does not have to be maximized, a diet providing 360 g protein kg<sup>-1</sup> diet may be utilized. At this protein level, the inclusion of 80 g dietary lipid kg<sup>-1</sup> diet is recommended. Because of the necessity of optimizing feed costs during all aspects of culture, and the potential for nutrient requirements to change as the fish ages, continued research with various production stages is recommended.

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