Aquaculture Reports 26 (2022) 101307

Contents lists available at ScienceDirect

Aquaculture Reports

journal homepage: www.elsevier.com/locate/aqrep

Growth, body composition, and survival of juvenile white bass (*Morone chrysops*) when dietary fish meal is partially or totally replaced by soybean meal, poultry by-product meal, an all-plant protein blend or a commercial plant-animal protein blend

Steven D. Rawles [a], Adam Fuller [a], Bartholomew W. Green [a], Jason W. Abernathy [a], David L. Straus [a], Michael B. Deshotel [a], Matthew E. McEntire [a], George Huskey [a], Kurt A. Rosentrater [b], Benjamin H. Beck [c], Carl D. Webster [a,*]

[a] USDA-ARS Harry K. Dupree Stuttgart National Aquaculture Research Center (HKDSNARC), PO Box 1050, 2955 Highway 130 East, Stuttgart, AR 72160, USA
[b] Iowa State University, 3327 Elings, 605 Bissell Rd., Ames, IA 50011, USA
[c] USDA-ARS Aquatic Animal Health Research Center (AAHRC), 990 Wire Rd., Auburn, AL 36832, USA

ARTICLE INFO

Keywords:
White bass
Morone chrysops
Diets
Fish meal replacement
Growth
Body composition
Alternative protein ingredients

ABSTRACT

White bass (*Morone chrysops*) is a popular sportfish throughout the southern United States, and one parent of the commercially successful hybrid striped bass (*M. chrysops ♂ x M. saxatilis ♀; HSB*). Commercial production of white bass does not currently exist in the U.S. due to a lack of information regarding nutritional requirements and cost-effective diets as well as high production costs. Currently, white bass are cultured using diets formulated for other carnivorous fish that contain a significant percentage of marine fish meal (FM). We evaluated growth, survival, and body composition of white bass fed diets in which FM was replaced by various protein ingredients including soybean meal (SBM), poultry by-product meal (PBM), a combination of SBM, canola meal, and soy protein concentrate, or a commercial protein blend (Pro-Cision™). Six isonitrogenous (40% protein), isolipidic (11%), and isocaloric (17.1 kJ/g) diets were formulated using nutrient availability data for most of the dietary ingredients. Fish (40.2 ± 1.83 g) were stocked into a flow-through (2 L/min) culture system (3 tanks/diet; 10 fish/tank) and fed the test diets twice daily (7 d/wk) to satiation for 60-d. Test diets that replaced FM with various percentages of SBM and PBM resulted in similar performance as fish fed the control diet containing 30% FM. Fish fed the all-plant diet or the diet in which the commercial blend replaced FM resulted in reduced growth performance. Diet performance rankings based on response measures along with differences in essential amino acids and feed intake provided some insight into differences in diet performance. White bass can be fed fish meal-free diets without significantly reducing growth; however, replacement of FM exclusively with plant protein or commercial protein blends may need further study to ensure sufficient intake and performance. Limiting amino acid balance will also need to be addressed in future FM replacement trials with white bass.

1. Introduction

White bass (WB); *Morone chrysops,* is an under-utilized fish in the United States but has the potential to become a valuable food-fish industry. Because no data on nutrient requirements are known for this species, and because it is carnivorous, WB typically are fed high-protein (> 40% crude protein) diets formulated for other commercially important carnivorous fish and contain significant marine fish meal (FM) content. Nutrient requirements or diet formulations for WB may be similar to the moronid hybrid striped bass (HSB), *M. chrysops ♂ x M. saxatilis ♀* and *M. saxatilis ♂ x M. chrysops ♀* (NRC, 2011), commonly called the sunshine bass, or similar to the centrarchid largemouth bass (LMB) *Micropterus salmoides* (Tidwell et al., 1996, 2005; Coyle et al., 2000; Portz et al., 2001). However, to date, there are no published reports of nutrient requirements or diet formulations for WB.

Partial or total replacement of FM by alternative protein sources can

---

* Corresponding author.
E-mail address: carl.webster@usda.gov (C.D. Webster).

https://doi.org/10.1016/j.aqrep.2022.101307
Received 16 May 2022; Received in revised form 16 August 2022; Accepted 16 August 2022

reduce feed cost and increase the sustainability of aquaculture diets. Much effort has been expended in evaluating moronid and LMB performance when FM is replaced with alternative protein sources. Soybean meal (SBM) and high-quality poultry by-product meal (PBM) can completely replace FM in diets for soy naïve HSB when formulated on an ideal protein basis and supplemented with Met, Lys, and Thr (Ramena et al., 2020). Rossi et al. (2021) found no adverse effects on LMB growth, body composition, and intestinal histomorphology when fed a diet containing 4% FM, 8% PBM, and 50% SBM compared to fish fed a diet containing 47% FM and 8% PBM when the SBM-based diet was supplemented with 2% Gly. Enzyme-treated SBM could replace 35% of the FM in diets for LMB (Liu et al., 2020), while replacement of FM in aquaculture diets with various soy products [e.g., SBM, soy protein concentrate (SPC) and soy protein isolate (SPI)] has been reported with varying degrees of success (Zhang et al., 2018; Yesilayer and Kaymak, 2020).

Canola is the name for varieties of rapeseed (*Brassica napus* and *B. campestris*) that have low levels of erucic acid and glucosinolates. Rapeseed (canola) is the second-most produced plant protein ingredient in the world after SBM and possesses favorable essential amino acid (EAA) composition, bioactive peptides (Akbari and Wu, 2015), and phenolic compounds that have antioxidant activity (Mazumber et al., 2016). However, use of canola meal (CM) in aquaculture diets is limited by the presence of antinutritional factors (ANFs) and high fiber levels (Webster et al., 1997a, 2000; Lim et al., 1998; Glencross et al., 2004; Ngo et al., 2016; Dossou et al., 2018).

Animal-protein ingredients, such as PBM, have variable success as partial or total alternatives to FM in diets for various fish. For several carnivorous fish, PBM is an excellent replacement for moderate-to-high percentages of FM (Nengas et al., 1999; Tidwell et al., 2005; Wang et al., 2015; Wu et al., 2018). Moreover, blends of animal and plant protein ingredients in aquafeeds often produce better production metrics because they reduce ingredient costs, provide complimentary nutrient profiles, especially vitamins and EAAs, that meet the animal's nutrient requirements (Webster et al., 1999), and reduce potential negative palatability issues associated with using predominantly one protein source (Webster et al., 1992). Commercial protein blends are available for use as FM substitutes in aquaculture diets, such as the Aqua-Pak Elite™ series and specifically, Pro-Cision™ (H.J. Baker Bros., Inc., Tuscola, TX, USA) that is comprised of proprietary combinations of animal and plant proteins that include PBM, meat and bone meal, feather meal, blood meal, corn gluten (CG), wheat gluten (WG), distiller's dried grains with solubles (DDGS), SPC, and SPI (McCann et al., 2021).

The objectives of this feeding trial were to evaluate growth, survival, and body composition of white bass fed diets in which FM was partially or totally replaced by a combination of SBM and PBM, and other plant proteins that included CM, SPC, WG, or the commercial protein blend Pro-Cision™.

2. Materials and methods

The experimental protocol was approved by the HKD-SNARC Institutional Animal Care and Use Committee and conformed to USDA Agricultural Research Service Policies and Procedures 130.4 and 635.1.

2.1. Experimental diets

Six isonitrogenous (40% protein), isolipidic (11%), and isocaloric (17.1 kJ/g) diets were formulated on an as-fed basis to meet the known nutrient and energy requirements of LMB (Webster et al., 1997b; Portz et al., 2001; Portz and Cyrino, 2004). The FM30 (control) diet was formulated like a high-quality, commercial carnivorous fish diet containing 30% FM and 37% SBM. The remaining test diets were formulated at a 40% protein inclusion level to have similar formulated nutrient composition as the control and replaced half or all of the FM in the control diet with other ingredients on a digestible protein basis as follows: FM15/SBM replaced half the FM protein with SBM; FM15/PBM replaced half the FM protein with PBM; FM0/PBM replaced all FM protein with PBM; FM0/PP replaced all FM protein with a combination of plant proteins (CM, SPC, WG), and FM0/Pro replaced all FM protein with the commercial protein blend Pro-Cision™ (H.J. Bakers Bros., Inc., Tuscola, TX, USA).

Essential amino acid (EAA) requirements were based on whole-body and fillet composition of LMB (Portz and Cyrino, 2003). Diets were formulated on a digestible protein basis or an available amino acid basis when available for FM, SBM, PBM, and wheat as determined in LMB (Portz and Cyrino, 2004), WG (da Silva and Oliva-Teles, 1998) and soy protein concentrate (Kaushik, 2002) as determined in European seabass, and CM as determined in HSB (Gaylord et al., 2004). Amino acid availabilities for WG, SPC, and CM in white bass are not published, but were assumed to be 90%. Nutrient requirements for LMB were used as it has been previously demonstrated that LMB can be fed a diet formulated to meet nutrient requirements of HSB (Tidwell et al., 2005) and LMB require some EAA at higher levels than HSB (NRC, 2011), e.g., Thr (Rahman et al., 2021), Lys (Dairiki et al., 2007), and Arg (Zhou et al., 2012). Lipid contribution from dry ingredients was balanced with canola oil and menhaden fish oil to maintain the diets isolipidic and isoenergetic, while the contribution of fish oil to total lipid was maintained constant in all diets by including 6% menhaden fish oil in the fish meal free diets.

All ingredients were ground in a pilot-scale hammermill (Viking, CPM Roskamp Champion, Waterloo, IA, USA), and then blended in a rotating mixer (Model 043206, Kobalt/Monarch Industries, Winnipeg, Canada). Extrusion was performed using a single-screw extruder (Model 500, Insta-Pro, Inc., Des Moines, IA, USA) with a 45 mm diameter screw and a 20:1 screw length to diameter (L/D) ratio. Feed blends were manually fed into the extruder at a constant rate. The extruder was connected to a 7.5 HP motor and screw speed was set at 600 RPM. A circular die plate (with multiple 3 mm holes) was attached to the extruder. The mass flow rate was determined by collecting extrudate samples at 30-sec intervals during extrusion processing and weighing the samples on an electronic balance. Observed mass flow rates ranged from 0.089 to 0.095 kg/s. The temperatures of the die and of the resulting pellets were recorded every two minutes using an infrared thermometer and determined to be 53 ± 5℃ at the die plate and 63–70 °C for the extrudates. After extrusion processing, the extrudates were air dried for 24 h, then bagged and frozen. Diets were stored at − 20 °C in plastic containers until fed.

2.2. Ingredient and diet analysis

Proximate and amino acid compositions of the ingredients (Table 1) and diets (Table 2) were measured by two commercial laboratories (Eurofins Scientific, Inc., Des Moines, IA, USA; Texas Agrilife Research, College Station, TX, USA) based on the Association of Official Analytical Chemists (AOAC) standard methods (AOAC, 2015) for moisture (AOAC 930.15), protein (AOAC 990.03), lipid (AOAC 954.02), fiber (AOAC 962.09), and ash (AOAC 942.05). Nitrogen-free extract (NFE, i.e., carbohydrate) was calculated by difference where NFE = 100 - (% protein + % lipid + % fiber + % ash). Available energy was estimated from the physiological fuel values of 16.7, 16.7, and 37.9 kJ/g for protein, carbohydrate (NFE), and lipid, respectively (Garling and Wilson, 1977; Webster et al., 1999). Amino acid composition of the diets (Table 3) were quantified by ultra-performance liquid chromatography (UPLC; Acquity System, Waters Corp., Milford, MA, USA) following the methodology described by Castillo et al. (2015). Diet available phosphorus (Table 1) was estimated from composition matrices and availability estimates for HSB (Barrows et al., 2016).

The concentration (%) and diet rank (#) of available P in each of the test diets was as follows: FM30 (0.66%, #4), FM15/SBM (0.56%, #5), FM15/PBM (0.72%, #3), FM0/PBM (0.74%, #2), FM0/PP (0.44%, #6),

Table 1
Proximate and selected amino acid composition (g/kg) of menhaden fish meal (FM), soybean meal (SBM), poultry by-product meal (PBM), soy protein concentrate (SPC), canola meal (CM) and a commercial protein blend (Pro-Cision™).

	Ingredient					
	FM	SBM	PBM	SPC	CM	Pro-Cision™
Moisture	71.0	100.6	48.0	33.0	70.0	66.6
Protein	660.2	516.2	658.6	706.0	365.0	704.2
Lipid	108.6	38.1	154.4	11.0	34.0	91.8
Ash	218.2	73.9	117.8	36.0	68.0	131.5
Amino acids						
Arg	34.4	37.3	43.8	51.0	23.2	39.8
Cys	4.9	6.7	10.9	8.9	9.7	11.8
His	14.2	12.9	5.8	18.0	11.0	18.2
Ile	26.4	22.3	21.3	32.0	15.1	24.9
Leu	32.5	38.2	40.4	55.0	26.0	53.6
Lys	48.0	30.9	31.0	45.0	20.2	47.1
Met	16.2	7.3	5.1	9.0	7.7	17.4
Phe	25.9	25.7	24.3	36.0	1.5	30.4
Thr	29.1	19.9	25.4	27.0	15.0	29.6
Trp	8.4	7.0	6.7	8.4	4.6	7.2
Tyr	18.9	17.4	15.6	23.0	9.9	18.0
Val	31.0	23.3	28.5	34.0	19.4	37.4

Table 2
Composition (g/kg; as-fed basis) of six practical test diets fed to juvenile white bass.

	Diet[2]					
	FM30	FM15/ SBM	FM15/ PBM	FM0/ PBM	FM0/ PP	FM0/ Pro
Ingredient[1]	1	2	3	4	5	6
FM	300.00	150.00	150.00	0.00	0.00	0.00
PBM	0.00	0.00	160.00	320.00	0.00	0.00
SBM	370.00	560.00	340.00	310.00	390.00	200.00
CM	0.00	0.00	0.00	0.00	100.00	0.00
SPC	0.00	0.00	0.00	0.00	150.00	0.00
WG	0.00	0.00	0.00	0.00	50.00	0.00
Pro-Cision™	0.00	0.00	0.00	0.00	0.00	400.00
Wheat	221.00	166.00	246.00	272.00	179.00	306.00
Canola oil	50.00	45.00	25.00	4.00	37.00	0.00
Menhaden fish oil	30.00	45.00	45.00	60.00	60.00	60.00
Dicalcium phosphate	20.00	25.00	25.00	25.00	25.00	25.00
Choline chloride	3.00	3.00	3.00	3.00	3.00	3.00
Stay C© (35%)	1.00	1.00	1.00	1.00	1.00	1.00
Vitamin mix[3]	4.00	4.00	4.00	4.00	4.00	4.00
Mineral mix[4]	1.00	1.00	1.00	1.00	1.00	1.00
Analyzed composition[5]						
Moisture	99.40	69.70	62.20	71.10	66.30	75.60
Protein	411.40	403.00	402.70	389.00	406.00	429.00
Lipid	108.60	105.50	107.50	101.80	106.90	98.20
Fiber	15.50	27.50	16.50	16.00	33.50	11.00
Ash	93.80	90.80	106.70	119.70	71.90	93.40
Available P[6]	6.60	5.60	7.20	7.40	4.40	13.20

[1] Ingredient designations and sources: FM, Special Select™ menhaden fish meal (Omega Protein Corp., Hammond, LA, USA); PBM, petfood grade poultry by-product meal (Tyson Foods, Inc., Sedalia, MO, USA); SBM, soybean meal (Dakotaland Feeds, Huron, SD, USA); CM, canola meal, (Rangen, Buhl, ID); SPC, soy protein concentrate (Profine VF, Solae Inc., Minneapolis MN, USA); WG, wheat gluten meal (Rangen, Buhl, ID, USA); Aqua-Pak Pro-Cision™ (HJ Baker Brothers, Inc., Tuscola, TX, USA); wheat (Rangen, Buhl, ID, USA); canola oil, (Rangen, Buhl, ID); menhaden fish oil (Omega Oils, Reedville, VA, USA); Stay C© 35 (DSM Nutritional Products, Basel, Switzerland).

[2] Diets designations are described in Section *2.1 Experimental diets.*

[3] Vitamin mix supplied the following (mg or IU/kg of diet): biotin, 0.64 mg; B_{12}, 0.06 mg; E (as alpha-tocopherol acetate), 363 IU; folacin, 9.5 mg; myo-inositol, 198 mg; K (as menadione sodium bisulfate complex), 3.7 mg; niacin, 280 mg; D-pantothenic acid, 117 mg; B_6, 31.6 mg; riboflavin, 57.4 mg; thiamin, 35.8 mg; D_1, 440 IU; A (as vitamin A palmitate), 6607 IU.

[4] Mineral mix supplied the following (g/kg of diet): zinc, 0.07 g; manganese, 0.02 g; copper, 0.002 g; iodine, 0.010 g.

[5] Dry-matter basis.

[6] Estimated from availability of P in dietary ingredients for hybrid striped bass according to Barrows et al. (2016). All diets met P requirement for hybrid striped bass (NRC, 2011).

and FM0/Pro (1.32%, #1). Similarly, using availability estimates from the literature and the methods of Koch et al. (2016), the sum of squared deviations (SSd) of essential amino acids in the test diets compared to that of diet 1 (fish meal control) and their rank order are as follows: FM30 (SSd=0, #1), FM15/SBM (SSd=306.8, #2), FM15/PBM (SSd=5918.2, #6), FM0/PBM (SSd=1022.0, #3), FM0/PP (SSd=1158.4, #4), and FM0/Pro (SSd=1504.6, #5).

2.3. Fish and culture system

White bass (40.21 ± 1.83 g; mean ± SE) were randomly stocked into 18, 200-L, round (2-ft dia.; 76 cm height) tanks at a density of 10 fish/tank (3 replicate tanks per dietary treatment). Water from a freshwater well was supplied at 2.0 L/min in a flow-through design. Fish were hand-fed their respective pelleted test diets twice daily (0700 and 1530; 7 d/wk) all they would consume in 20 min for the 60-d feeding trial. Mortalities were replaced during the first week of the feeding trial. Light was provided by overhead fluorescent ceiling lights set on a photoperiod of 15 h:9 h light:dark cycle. All tanks were siphoned daily to remove uneaten diet and feces. If present, mortalities were recorded and removed daily. All tanks were covered with polyethylene mesh to prevent fish loss due to escapement or jumping to adjacent tanks.

Dissolved oxygen (DO) and water temperature (°C) were measured daily (Model 556MPS, YSI, Inc., Yellow Springs, OH, USA). Alkalinity, hardness, chlorides, total ammonia nitrogen (TAN), nitrite, nitrate, and pH were recorded weekly. TAN and nitrite nitrogen were analyzed by multiparameter colorimeter (Model DR 900, Hach, Co., Loveland, CO, USA) using the salicylate method (TAN) and azo-dye method (nitrite nitrogen). Average water quality parameters (± SE) during the feeding trial were 22.5 ± 0.1°C water temperature, 7.99 ± 0.03 mg DO/L, 0.03 ± 0.01 mg TAN/L, 0.01 ± 0.00 mg nitrite/L, 191.5 ± 1.9 mg total alkalinity/L, 110.8 ± 1.4 mg hardness/L, 202.1 ± 3.1 mg chloride/L, and a pH of 8.14 ± 0.12. All parameters were within acceptable limits for fish growth and health (Boyd, 1979).

2.4. Data collection and sample analysis

Fish were not fed for 18-h prior to the conclusion of the study. Subsequently, fish in each tank were enumerated to determine survival (%), individually weighed to the nearest 0.01 g on an electronic scale (Model AB54-S; Mettler Toledo, Columbus, OH, USA), and measured for total length to the nearest 0.1 mm. Seven fish in each tank were randomly selected and euthanized with 300 mg/L MS-222 and examined for hepatosomatic index (HSI) and viscerosomatic index (VSI) and whole body composition.

Whole-body proximate analysis was performed by a commercial laboratory (Mississippi State Chemical Laboratory, Mississippi State University, Starkville, MS, USA). Whole bodies were homogenized twice through a meat grinder and pooled per tank prior to analysis. Pooled tissue samples were analyzed as described for the diet analysis except for whole body protein and lipid. Whole body protein was determined by the Dumas method (AOAC 992.15) using a protein/nitrogen analyzer (Model FP-528, Leco Inc, St Joseph, MI, USA) while lipid was determined by solvent extraction with 2:1 chloroform:methanol at 100°C (AOAC 991.36; 960.39). Whole body homogenates from each tank were analyzed in duplicate for amino acid profiles by the Fish Nutrition Laboratory at Texas A&M University (College Station, TX).

Table 3

Amino acid composition (g/kg; as-fed basis) of six test diets fed to juvenile white bass.

	Diet					
	FM30	FM15/SBM	FM15/PBM	FM0/PBM	FM0/PP	FM0/Pro
Amino acid	1	2	3	4	5	6
Essential						
Arg	23.6 ± 1.1	23.8 ± 1.5	32.4 ± 1.5	27.7 ± 1.5	23.6 ± 0.2	21.5 ± 1.8
His	11.9 ± 0.6	12.3 ± 0.5	14.8 ± 0.7	13.3 ± 0.7	12.2 ± 0.1	12.5 ± 1.2
Ile	15.9 ± 0.6	15.4 ± 0.9	20.6 ± 1.0	16.5 ± 0.9	14.5 ± 0.4	19.1 ± 0.6
Leu	28.8 ± 1.1	27.6 ± 1.4	38.0 ± 1.8	30.8 ± 1.6	27.8 ± 0.1	27.2 ± 1.9
Lys	28.3 ± 1.3	28.2 ± 1.3	24.0 ± 2.0	24.5 ± 1.3	24.1 ± 2.8	22.8 ± 1.5
Met	7.4 ± 1.7	6.7 ± 0.3	6.8 ± 1.0	6.1 ± 0.7	5.6 ± 2.6	8.3 ± 3.3
Phe	19.6 ± 1.1	17.5 ± 0.9	22.5 ± 4.0	18.7 ± 0.8	17.8 ± 0.1	18.0 ± 0.9
Thr	18.5 ± 0.8	17.0 ± 0.9	22.8 ± 1.1	18.3 ± 0.9	16.6 ± 0.7	14.8 ± 1.2
Val	18.4 ± 0.9	18.2 ± 0.8	24.3 ± 1.2	19.0 ± 1.0	16.9 ± 1.3	18.7 ± 1.9
Non-essential						
Ala	18.5 ± 0.5	16.5 ± 0.8	26.3 ± 1.3	22.2 ± 1.2	14.5 ± 0.2	17.6 ± 1.4
Asp	25.7 ± 0.7	26.5 ± 1.4	35.8 ± 1.7	28.6 ± 1.5	25.8 ± 0.4	20.8 ± 2.6
Cys	4.6 ± 0.2	4.5 ± 0.3	6.4 ± 0.3	5.1 ± 0.3	3.7 ± 1.9	6.8 ± 0.7
Gln-Glu[1]	44.7 ± 0.8	45.1 ± 1.7	64.8 ± 3.1	54.8 ± 2.8	56.6 ± 1.1	39.8 ± 3.6
Gly	21.2 ± 0.7	19.2 ± 1.1	32.9 ± 1.5	31.2 ± 1.6	28.9 ± 0.7	24.1 ± 1.7
Hpro-Pro[2]	28.1 ± 0.7	26.5 ± 1.1	40.7 ± 1.9	38.7 ± 2.0	33.7 ± 0.3	33.3 ± 1.8
Ser	17.4 ± 0.3	18.0 ± 1.0	24.7 ± 1.2	20.5 ± 1.1	19.9 ± 0.0	22.1 ± 1.5
Tau	4.1 ± 0.1	4.3 ± 0.2	5.9 ± 0.3	4.9 ± 0.3	4.7 ± 0.8	5.1 ± 0.6
Tyr	11.2 ± 1.9	13.3 ± 3.8	11.3 ± 0.5	11.0 ± 0.6	9.8 ± 2.1	8.9 ± 1.4

[1] Glutamine/Glutamic acid.

[2] Hydroxyproline/Proline.

2.5. Calculations

Metrics of growth and composition of growth were assessed at the conclusion of the feeding trial according to the following equations:

Weight gain (%) = 100 [$(W_f – W_i) / W_i$], where W_f and W_i are final and initial fish weight (g), respectively·

Specific growth rate (SGR; %/d) = 100 [$(\ln W_f – \ln W_i) / t$], where t is time (d) fed·

Feed conversion ratio (FCR) = dry diet intake (g) / wet weight gain of fish (g)·

Hepatosomatic index (HSI; %) = (liver weight (g) x 100) / fish weight (g)·

Viscerosomatic index (VSI; %) = (viscera weight (g) x 100) / fish weight (g)·

Within each response, diets were ranked as described by Webster et al. (2021). Mean diet ranks were then calculated and ordered to assign overall diet rank order (Table 4).

2.6. Statistical analysis

Growth, body composition, and survival data were analyzed using PROC GLM in SAS version 9.4 (SAS Institute, Cary, NC, USA) to determine if significant differences ($P < 0.05$) existed among treatment means according to Tukey's multiple comparison technique (Zar, 1984). All data were log-transformed prior to statistical analysis.

Table 4

Growth, composition indices, and diet rankings of juvenile white bass (initial average weight, 40.1 ± 1.83 g) fed six diets containing various percentages of fish meal. Means (± SE) within a row with different letters are different ($P <$ 0.05).[1].

	Diet					
	FFM30	FM15/SBM	FM15/PBM	FM0/PBM	FFM0/PP	FM0/Pro
Response	1	2	3	4	5	6
Survival (%)	96.7^{a}	100.0^{a}	100.0^{a}	100.0^{a}	100.0^{a}	100.0^{a}
(SE)	(3.3)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Final weight (g)	86.7^{abc}	92.7^{ab}	84.7^{bc}	101.5^{a}	78.7^{bc}	74.4^{bc}
(SE)	(3.24)	(4.35)	(3.99)	(4.27)	(4.82)	(2.97)
Rank	*3*	*2*	*4*	*1*	*5*	*6*
Weight gain (%)	130.5^{ab}	160.4^{ab}	142.8^{ab}	183.7^{a}	142.9^{ab}	102.5^{b}
(SE)	(13.3)	(1.9)	(27.4)	(18.6)	(13.3)	(7.4)
Rank	*5*	*2*	*4*	*1*	*3*	*6*
SGR (%/d)	1.34^{abc}	1.56^{ab}	1.31^{abc}	1.60^{a}	1.19^{bc}	1.1^{c}
(SE)	(0.04)	(0.1)	(0.10)	(0.10)	(0.12)	(0.02)
Rank	*3*	*2*	*4*	*1*	*5*	*6*
FCR	1.78^{a}	1.62^{a}	1.77^{a}	1.56^{a}	1.71^{a}	1.98^{a}
(SE)	(0.07)	(0.01)	(0.18)	(0.06)	(0.07)	(0.07)
Rank	*5*	*2*	*4*	*1*	*3*	*6*
HSI (%)	2.01^{b}	1.45^{c}	1.84b	2.34^{a}	1.52^{c}	2.46^{a}
(SE)	(0.06)	(0.06)	(0.08)	(0.03)	(0.05)	(0.09)
Rank	*3*	*6*	*4*	*2*	*5*	*1*
VSI (%)	4.19^{a}	4.27^{a}	4.04^{a}	4.50^{a}	4.22^{a}	4.42^{a}
(SE)	(0.12)	(0.14)	(0.11)	(0.09)	(0.73)	(0.11)
Rank	*5*	*3*	*6*	*1*	*4*	*2*
Mean rank	*4*	*2.8*	*4.3*	*1.2*	*4.2*	*4.5*
Rank order	*3*	*2*	*5*	*1*	*4*	*6*
EAA SSd[2]	0	306.8	5918.2	1022	1158.4	1504.6
Rank	*1*	*2*	*6*	*3*	*4*	*5*
Intake (g dwb[3])	813.4^{ab}	974.0^{ab}	915.6^{ab}	1059.6^{a}	911.9^{ab}	753.1^{b}
(SE)	(27.5)	(7.1)	(103.3)	(69.6)	(50.2)	(27.4)
Rank	*5*	*2*	*3*	*1*	*4*	*6*

[1] Abbreviations for responses defined in Section *2.5 Calculations* include: SGR specific growth rate; FCR, feed conversion ratio; HSI, hepatosomatic index; VSI, viscerosomatic index.

[2] EAA SSd, sum of squared deviations from the essential amino acid profile of the fishmeal control (#1) diet.

[3] dwb, dry weight basis.

3. Results

3.1. Growth, condition factor, diet utilization, and body composition

The highest final weight, weight gain, SGR, HSI, VSI, and lowest FCR were observed for fish fed FM0/PBM. The lowest final weight, weight gain, SGR, VSI, and highest FCR were observed for fish fed FM0/Pro. Although final individual weight, percentage weight gain, and SGR of fish fed FM0/Pro was significantly lower ($P < 0.05$) than those of fish fed FM0/PBM, fish fed the other diets (Diets 1–3; FM0/PP) did not significantly differ from each other (Table 4). Fish fed FM0/PP had significantly lower final weight and SGR compared to fish fed FM0/PBM but were not different from fish fed the other test diets. FCR, survival, and VSI were not significantly different among dietary treatments and averaged 1.74, 99.4%, and 4.27, respectively; however, HSI for fish fed FM15/SBM and FM0/PP were significantly lower compared to fish fed the other diets (Table 4). Further, fish fed FM30 (control) and FM15/PBM had significantly lower HSI compared to fish fed FM0/PBM and

FM0/Pro.

Whole-body composition (fresh-weight basis) of white bass fed diets with total replacement of FM by SBM, PBM, all-plant protein, or ProCision™ was not significantly different from that of fish fed the diet containing 30% FM (FM30, control) or fish fed the two 15% FM diets (FM15/PBM; FM15/SBM) and averaged: 68.88% moisture, 19.10% protein, 7.61% lipid, 1.49% fiber, and 5.30% ash, respectively (Table 5). Generally, there were few significant differences in EAA profiles of whole-body white bass fed the different tests diets (Table 6). Fish fed FM15/SBM had a significantly greater Thr (2.71%)compared to fish fed FM0/PBM (2.51%). Among non-essential amino acids (NEAA), only Ala and Tau were found to be significantly different among fish fed the various diets (Table 6). Fish fed FM0/Pro (4.70%) had a significantly greater Ala compared to fish fed FM0/PBM (4.37%), while fish fed FM30 (0.53%) had a significantly more Tau compared to fish fed FM15/SBM (0.34%), FM0/PBM (0.37%), and FM0/PP (0.38%; Table 6).

3.2. *Diet rankings*

Rank order of the mean performance metrics, sum of squared deviations from the essential amino acid profile (EAA SSd) of the control diet, and total feed intake are presented in Table 4. Ranking of the performance metrics suggest the order of overall diet performance was as follows:

#1 (FM0/PBM) > #2 (FM15/SBM) > #3 (FM30) > #4 (FM0/PP) > #5 (FM15/PBM) > #6 (FM0/Pro).

In contrast, the rank order of the sum of squared deviations from the essential amino acid profile (EAA SSd) of the control diet, show the following order:

#1 (FM30) > #2 (FM15/SBM) > #3 (FM0/PBM) > #4 (FM0/PP) > #5 (FM0/Pro) > #6 (FM15/PBM).

Total feed intake only differed significantly between FM0/PBM (1059.6 g) and FM0/Pro (753.1 g) with significant overlap in feed intake with the remaining diets (813.4 – 974.0 g); however, when ranked, the order of total feed intake was as follows:

#1 (FM0/PBM) > #2 (FM15/SBM) > #3 (FM15/PBM) > #4 (FM0/PP) > #5 (FM30) > #6 (FM0/Pro).

4. Discussion

This is the first published study to evaluate partial to total replacement of FM in diets for WB. As diets were formulated to meet the nutrient requirements of largemouth bass, the present data indicate that refinements in diet formulation are required. In particular, attention to palatability is needed when formulating alternative protein diets for white bass as the current data suggest issues with total feed intake relative to ingredient combinations. The test diets were formulated isonitrogenous and isolipidic; however, minor differences in proximate compositions were reported after analysis that are most likely due to differences in nutrient compositions of the ingredients used to produce the diets compared to the ingredients used in the initial nutrient determinations. Nevertheless, in spite of few statistical differences among performance metrics, body composition, and feed intake, the significant difference in feed intake between diets FM0/PBM and FM0/Pro, combined with the few statistical differences in performance traits attributable to those two diets suggest that feed intake was the major influence on diet performance and not differences in the essential amino acid profiles of the test diets. This is corroborated by the overall diet performance rankings which nearly match up with the rankings of feed intake, except for the reversed rankings for FM30, which was performance rank #3 and intake rank #5, compared to FM15/PBM, which was performance rank #5 and intake rank #3. At that point, the stark difference in EAA profiles between FM30 (EAA SSd rank #1) and FM15/PBM (EAA SSd rank #6) allowed for better performance for FM30. The addition of PBM in FM15/PBM at the expense of FM in the FM30 formula probably resulted in imbalances in limiting amino acids that contributed to the poorer performance of FM15/PBM.

Table 5
Mean (± SE) whole-body proximate composition (g/kg fresh weight) of juvenile white bass fed diets containing various percentages of fish meal. There were no significant differences ($P > 0.05$).

	Diet					
Composition[1]	FM30	FM15/SBM	FM15/PBM	FM0/PBM	FM0/PP	FM0/Pro
	1	2	3	4	5	6
Moisture	684.3 ± 1.1	681.2 ± 10.9	682.4 ± 8.9	687.7 ± 5.7	695.3 ± 7.7	701.8 ± 6.5
Protein	191.0 ± 3.7	198.4 ± 6.2	195.4 ± 7.5	186.2 ± 2.6	187.4 ± 2.7	187.3 ± 2.6
Lipid	75.4 ± 2.7	76.5 ± 4.2	74.4 ± 5.7	85.3 ± 6.5	78.1 ± 4.5	67.0 ± 2.9
Fiber	14.6 ± 1.8	15.4 ± 4.6	17.6 ± 0.8	13.6 ± 1.3	13.4 ± 1.6	14.6 ± 0.7
Ash	51.9 ± 5.2	50.5 ± 4.6	59.3 ± 2.1	54.8 ± 3.4	49.2 ± 1.3	52.1 ± 2.1

[1] Values are means from duplicate determinations on 7 fish/tank from $N = 3$ tanks per diet.

4.1. *Survival, feed conversion ratio (FCR), and viscerosomatic index (VSI)*

In the present study, no differences were found in survival, FCR, and VSI, and only minor differences in HSI were seen in fish fed the various diets. In fact, FM can be replaced completely with animal and plant protein ingredients in formulated diets with no adverse effect on white bass performance. However, WB performance suffers when fed an all-plant protein diet. This agrees with Watson et al. (2014) who reported that growth, SGR, PER, FCR, and body composition of juvenile cobia, *Rachycentron canadum*, were not different when fish were fed a control diet containing 45% FM or diets containing up to 60% of selected, non-genetically modified (non-GMO) SBM replacing FM. However, while feed intake did not differ among black sea bass, *Centropristis striata,* fed diets containing increasing percentages of PBM, FCR and PER were significantly higher and lower, respectively, in fish fed a diet containing 0% FM and 62.7% PBM compared to fish fed a control diet containing 70% FM and 0% PBM (Dawson et al., 2018). Although Monge-Ortiz et al. (2018) reported no significant differences in final weight of Mediterranean yellowtail, *Seriola dumerili,* fed a diet containing 0% FM, 34.5% krill meal, and 25% meat meal compared to fish fed a diet containing 52.5% FM, an examination of the data reveals that fish fed the FM-free diet had final weights that were numerically14% less than weights of fish fed the diet containing FM. Further, fish fed the FM-free diet had significantly reduced survival (23%) compared to fish fed all other dietary treatments (range 75–86%). Although no causative agent for the reduced survival was reported, it has been noted that fish fed FM-free diets can have reduced immune system function (Estruch et al., 2015).

4.2. *Whole body composition*

Partial or total replacement of FM in diets for white bass in the current study did not affect WB whole-body proximate and amino acid compositions regardless of dietary protein source. Similarly, an all-plant diet did not affect whole-body proximate composition of Nile tilapia, *Oreochromis niloticus* (Thompson et al., 2012). Whole-body lipid content was not significantly different among black sea bass fed diets containing various percentages of PBM indicating that lipid in PBM was efficiently utilized by the fish (Dawson et al., 2018). This has also been reported in other fish species (El-Sayed, 1998; Webster et al., 1999; Takakuwa et al., 2006; Shapawi et al., 2007; Zhou et al., 2011).

These reports contrast with others that have shown that lipid content

Table 6
Whole-body amino acid composition (g/kg dry matter, ± SE) of juvenile white bass fed diets containing various percentages of fish meal. Means within a row with different letters were significantly different ($P < 0.05$). Values are means from duplicate determinations on 7 fish/tank from $N = 3$ tanks per diet.

	Diet					
	FM30	FM15/SB	FM15/PB	FM0/PB	FM0/PP	FM0/Pro
Amino acid	1	2	3	4	5	6
Essential						
Arg	40.5 ± 0.6	41.3 ± 0.9	40.5 ± 0.1	38.2 ± 2.0	40.3 ± 0.6	40.5 ± 1.0
His	12.8 ± 0.3	12.6 ± 0.3	12.0 ± 0.2	11.6 ± 1.9	12.3 ± 0.6	12.3 ± 0.4
Ile	24.2 ± 0.5	24.1 ± 0.1	23.5 ± 1.3	22.7 ± 0.5	23.9 ± 0.2	23.8 ± 0.1
Leu	43.4 ± 0.8	43.8 ± 0.6	42.3 ± 1.9	40.9 ± 0.6	43.3 ± 0.3	43.3 ± 0.1
Lys	38.1 ± 1.0	38.3 ± 1.1	38.9 ± 2.0	35.8 ± 1.4	38.3 ± 0.8	36.1 ± 1.4
Met	18.6 ± 0.4	18.7 ± 0.4	18.1 ± 0.5	17.4 ± 0.1	18.3 ± 0.1	18.6 ± 0.2
Phe	27.4 ± 0.6	28.0 ± 1.2	25.8 ± 0.6	25.4 ± 0.7	27.4 ± 0.3	27.4 ± 1.1
Thr	26.7 ± 0.3^{ab}	27.1 ± 0.5^{a}	26.1 ± 0.7^{ab}	25.1 ± 0.3^{b}	26.7 ± 0.2^{ab}	26.9 ± 0.2^{ab}
Val	27.7 ± 0.5	28.0 ± 0.2	27.2 ± 1.1	26.2 ± 0.6	27.4 ± 0.2	27.7 ± 0.1
Non-Essential						
Ala	45.7 ± 0.9^{ab}	46.1 ± 0.3^{ab}	46.0 ± 0.3^{ab}	43.7 ± 0.4^{b}	45.2 ± 0.7^{ab}	47.0 ± 0.5^{a}
Asn/Asp[1]	50.5 ± 1.2	50.1 ± 0.3	50.0 ± 1.8	47.8 ± 0.7	50.0 ± 0.9	50.2 ± 0.5
Cys	1.5 ± 0.1	1.4 ± 0.1	1.3 ± 0.1	1.3 ± 0.0	1.4 ± 0.0	1.4 ± 0.1
Gln/Glu[2]	82.4 ± 1.1	83.1 ± 1.0	81.3 ± 2.7	78.4 ± 0.7	81.3 ± 1.3	83.4 ± 1.3
Gly	32.6 ± 0.4	32.9 ± 0.7	32.9 ± 1.8	30.9 ± 0.4	31.3 ± 0.5	34.6 ± 1.7
Hpro[3]	14.7 ± 0.4	14.8 ± 0.5	15.6 ± 1.6	14.4 ± 0.6	13.7 ± 0.2	16.3 ± 1.0
Pro	37.6 ± 0.5	38.0 ± 0.4	38.4 ± 1.5	36.0 ± 0.4	37.3 ± 0.5	39.2 ± 1.2
Ser	27.6 ± 0.4	27.6 ± 0.7	26.6 ± 0.3	26.0 ± 0.3	27.3 ± 0.3	27.9 ± 0.5
Tau	5.3 ± 0.2^{a}	3.4 ± 0.1^{c}	4.5 ± 0.1^{ab}	3.7 ± 0.1^{bc}	3.8 ± 0.3^{bc}	4.5 ± 0.2^{ab}
Tyr	18.0 ± 0.4	18.4 ± 0.7a	17.5 ± 0.7	16.7 ± 0.4	18.3 ± 0.2	17.3 ± 0.2

[1] Asparagine/Aspartic acid.
[2] Glutamine/Glutamic acid.
[3] Hydroxyproline.

of fish fed high levels of PBM affected lipid profiles in fish (Nengas et al., 1999; Gonzalez-Rodriguez et al., 2016; Karapanagiotidis et al., 2019). Dawson et al. (2018) reported whole-body moisture and ash contents were significantly higher in black sea bass fed diets containing 50–100% PBM compared to fish fed a control diet without PBM. Increased ash content might be due to reduced ash digestibility in black sea bass when fed PBM compared to FM. This increased whole-body ash contents of fish fed diets containing PBM has been reported by others (El-Sayed, 1998; Shapawi et al., 2007).

4.3. Poultry by-product (PBM) diet performance

Varied effects on fish composition have been reported for replacement of FM with PBM. When PBM was used to replace FM, no effect on whole-body proximate composition was reported in diets for LMB (Subhadra et al., 2006; Ren et al., 2017), HSB (Thompson et al., 2007; Pine et al., 2008; Rawles et al., 2011), and Nile tilapia (Webster et al., 2016). No significant differences in whole-body protein content in black sea bass were reported by Dawson et al. (2018) which agrees with other published reports (Nengas et al., 1999; Takakuwa et al., 2006; Shapawi et al., 2007). This would indicate high digestibility of protein from PBM and is supported by the published protein digestibility values of PBM for black sea bass (82–84%; Dawson et al., 2018) and the sunshine HSB (Metts et al., 2011).

Among animal-source ingredients evaluated as FM replacements, PBM is generally a suitable replacement because of its high protein content, high amino acid digestibility, reasonable cost, availability, and palatability (Webster et al., 2000; Portz and Cyrino, 2004; Tidwell et al., 2005; Muzinic et al., 2006; Subhadra et al., 2006; Shapawi et al., 2007; Metts et al., 2011; Rawles et al., 2011; Rossi and Davis, 2012; Wang et al., 2015). However, its replacement value is highly dependent on the consistency and quality of the PBM with respect to the proportions of various tissue parts including heads, feet, and bones (excluding feathers and viscera) and their sources in the final product. High ash and keratin content, for example, can lead to reduced digestibility of nutrients resulting in lower growth rates in fish at higher dietary inclusion levels. Indeed, lower inclusion levels of PBM in the diet appears necessary to optimize growth in marine fish compared to freshwater fish (Nengas et al., 1999; Kureshy et al., 2000; Dawson et al., 2018).

4.4. Pro-Cision™ diet performance

The reduced growth of WB fed a diet containing 40% Pro-Cision™ (FM0/Pro) was surprising as it has been reported that bluegill fed a diet containing this percentage of the blended product had similar growth performance as fish fed a control diet containing 30% FM (Webster et al., 2021). However, McCann et al. (2021) reported that HSB fed a diet with 16.55% Pro-Cision™ and 0% FM exhibited reduced final weight and feed intake, while HSI and intraperitoneal fat levels were higher compared to fish fed a diet containing 16.67% FM. This was in spite of the fact that McCann et al. (2021) formulated all diets to contain adequate levels of all EAAs based upon the ideal protein concept so that EAA levels should not have been limiting. Likewise, the authors reported that digestibility of Pro-Cision™ by HSB was high, with a protein digestibility of 89.3% and all EAAs over 90% available (McCann et al., 2021). Thus, it may be that the protein-blended product was not as palatable as FM as intake was reduced in that study when HSB were fed the diet containing Pro-Cision™. Because the composition of Pro-Cision™ is a proprietary blend of various animal and plant proteins, it cannot be determined which ingredient(s) affected palatability; however, plant ingredients have been shown to reduce palatability (Rawles et al., 2011) and reduce apparent digestibility coefficients in HSB (Rawles et al., 2006, 2011; Barrows et al., 2016).

4.5. All-plant diet performance

The reduced growth of white bass fed the all-plant diet (FM0/PP) compared to FM0/PBM was unexpected as the diet was formulated to meet nutrient requirements of largemouth bass, and several plant-protein sources were utilized to keep inclusion levels below potentially problematic levels reported in the literature. However, the reduced growth observed in the present study agrees with other published data. Le Boucher et al. (2014) reported that growth of European sea bass, *Dicentrarchus labrax*, fed an all-plant diet was significantly reduced compared to fish fed a diet containing 38% FM.

Reduced palatability of all-plant protein diets is the main disadvantage reported compared to aquafeeds formulated using FM (Cho et al., 1974; Anderson et al., 2016; Wang et al., 2020). Palatability can be influenced by the levels of ANFs or desirable/undesirable flavors, or both. However, there may be species-specific tolerances for these two factors that could explain differences reported in the literature for the influence of diet palatability. Despite the reduced growth of WB fed an all-plant protein diet compared to those fed diets formulated using FM and PBM, there were no significant differences in FCR among dietary treatments in the current study. Thus, while growth may have been reduced in fish fed the all-plant diet, it does not appear that palatability was the primary reason.

Secondly, the EAA composition of many plant proteins is often inferior to those of FM and other animal-source proteins, resulting in deficiencies that reduce nutrient utilization and growth. Indeed, the largest SSd in essential amino acids compared to the FM control (FM30) was observed in FM0/Pro as well as the second largest SSd in total available amino acids (essential + non-essential). Deficiency of first-limiting amino acids such as Lys, Met, and Thr appear to be the most common problem with EAA content of all-plant diets and are further discussed in Section *4.7 Essential amino acid (EAA) supplementation* vs. *diet performance.* However, plant protein sources are often deficient in Tau, which can be conditionally essential for some fish, particularly marine species, in that it may not be biosynthesized *de novo* in amounts required during certain times (e.g., spawning and rapid juvenile growth). Wu et al. (2021) reported that addition of 0.5% Tau to diets for LMB increased growth without adverse effects on body composition or nutrient utilization when fish were fed a diet containing 49% SBM compared to fish fed diets containing less than 37% SBM. Taurine supplementation also improved growth of dentex, *Dentex dentex* (Chatzifotis et al., 2008); red sea bream, *Pagrus major* (Takagi et al., 2010); Florida pompano, *Trachinotus carolinus* (Rossi and Davis, 2012); yellowtail (Takagi et al., 2008), and golden pompano, *Trachinotus ovatus* (Wu et al., 2015) On the other hand, Tau supplementation resulted in no improvement in growth in Japanese flounder, *Paralichthys olivaceus* and common carp, *Cyprinus carpio* (Kim et al., 2008). Suehs and Gatlin (2021) reported that Tau addition did not improve growth performance or whole-body composition in HSB when supplemented to an SBM-based diet which met all known EAA requirements. Koch et al. (2016) also found Tau supplementation had no effect on growth or body composition in Nile tilapia fed diets containing adequate EAA, especially Met. As Tau is a free sulfonic acid, there is potential for interaction of Met and Tau through L-cysteine sulfinate decarboxylase (CSD) or cysteine sulfinate decarboxylase (CSA) pathways. Sufficient dietary Met could spare Tau requirement in fish; however, if Met is limiting, Tau supplementation may be required in larger amounts for optimal fish growth and health (Candebat et al., 2020).

Thirdly, plant-protein ingredients often contain ANFs that can adversely affect growth, nutrient utilization, and fish welfare. Among ANFs are protease inhibitors, hormone inhibitors (such as glucosinolates), phytate phosphorus (an unavailable source of phosphorus), complex carbohydrates, and high fiber. These factors can severely reduce nutrient digestibility and palatability, which can dramatically reduce fish growth. Indeed, the lowest level of estimated available P (0.44%) was found in FM0/Pro; this and putatively higher levels of phytate P in this diet suggests that dietary P may have been deficient. Deficient P as well as the lowest level of dietary starch energy may have resulted in the poorer performance of this diet.

Lastly, lack of n-3 highly unsaturated fatty acids and n-3 polyunsaturated fatty acids (n-3 HUFA/n-3 PUFA) in plant-protein ingredients may cause a deficiency of these essential lipids in fish leading to a reduction in growth; however, all diets were formulated to have similar fatty acid compositions so this explanation may not be viable for this feeding trial.

4.6. Canola meal (CM) diet performance

Canola meal (CM) is a widely used plant protein ingredient for animal and aquaculture diets. While the EAA composition of CM is favorable for its inclusion in many fish diets (Higgs et al., 1982; Davies et al., 1990; Webster et al., 1997a; Burel et al., 2000, 2001; Glencross et al., 2004), the meal has numerous ANFs that limit its use (Francis et al., 2001). These include indigestible carbohydrates, phytate, glucosinolates, and phenolic compounds. Glucosinolates reduce palatability and nutrient uptake which often limits the amount of RM/CM that can be added to a diet. Webster et al. (1997a) reported that a diet containing between 12% and 36% CM was acceptable for channel catfish, *Ictalurus punctatus*; however, a diet containing 48% CM resulted in reduced growth compared to fish fed a diet without CM containing 8% FM. This range of inclusion of CM in fish diets agrees with Cheng et al. (2010) who reported that 20% CM could be added to a diet for Japanese seabass, *Lateolabrax japonicus,* without adverse effects on growth, and 32% CM could be added to diets for grass carp, *Ctenopharyngodon idellus,* without a reduction in growth; however, higher inclusion levels resulted in reduced growth. Dossou et al. (2018) reported that juvenile red seabream (*Pagrus major*) could have 42% fermented rapeseed meal in a diet without adverse effects in growth, body composition, and blood composition. Cobia, *Rachycentron canadum*, however, cannot have more than 12.5% CM in a diet before reduced growth was observed (Luo et al., 2012). Likewise, Bu et al. (2018) stated that diets for the Ussuri catfish, *Pseudobagrus ussauriensis,* could have 17% CM added without negative effects on growth and feed conversion. Hence, differences in inclusion level of CM may be due to species, diet formulation, genetics, and culture conditions. In the present study, CM was limited to 10% in the all-plant-protein diet (FM0/PP) to avoid possible negative effects of ANFs.

4.7. Essential amino acid (EAA) supplementation vs. diet performance

In the present study with WB, the test diets were formulated to meet the known requirements of a centrarchid (largemouth bass) and no supplemental amino acids were added. Addition of limiting crystalline amino acids to offset the sum of ingredient deficiencies may or may not have improved the growth of WB fed diets with large (>60%) reductions in FM. To examine this proposition, we assumed momentarily that the fillet amino acid profile from WB fed the FM control diet (Table 6, FM30) represents a reasonable ideal protein target. Using previously noted amino acid availability estimates from the carnivorous fish literature, it can be shown that the first four limiting amino acids in the test diets are Met > Arg > Lys > Thr. Performance (growth and fat depots) rankings do not correlate with sum of squared deviations from ideal for the EAAs; however, performance rankings do correlate with sum of squared deviations from ideal of all (total = EAA + NEAA) amino acids for diets FM30 (Rank #3), FM15/PBM (Rank #5), and FM0/Pro (Rank #6). In the lowest ranked performing FM0/Pro diet, Met, Arg, Lys, and Thr were 55.1%, 46.7%, 40%, and 44.4% deficient, respectively, compared to the ideal model. Although the level of deficiency (55.1%) for Met in FM0/Pro was the lowest among the test diets, the levels of deficiency for Arg (46.7%), Lys (40%), and Thr (44.4%) in FM0/Pro were the highest for those amino acids among all the test diets.

Nevertheless, based on both the hypothetical ideal protein target analysis and the statistical differences among diets for each response measure, it may be that supplementation of the all-plant protein diet (FM0/PP) and the diet containing a protein blended product (FM0/Pro) with first limiting amino acids might have improved its performance; whereas, similar supplementations of the other test diets probably might not have yielded great improvements in performance compared to the FM control (FM30). Wu et al. (2018) reported, for example, that addition of 0.3–0.4% Met and 0.6–0.8% Lys did not improve growth of giant croaker (*Nibea japonica*) when fed diets containing 60–80% less FM compared to fish fed a control diet containing 40% FM. Further, improvement in diet consumption, possibly using attractants in the diet, might also have improved performance in FM0/PP and FM0/Pro as performance rankings better correlate with feed intake except for reversed rankings for FM30 and FM15/PBM. For performance, FM30 was ranked #3 and FM15/PBM was ranked #5, whereas for intake, FM30 was ranked #5 and FM15/PBM was ranked #3. This seeming discrepancy (higher intake but lower performance of FM15/PBM) can be explained by the larger sum of squared deviations from the ideal profile that was found in FM15/PBM (1.57×10^5) compared to that of FM30 (0.78×10^5).

5. Conclusion

The findings from the present study indicate that juvenile white bass can be fed diets without fish meal without negative effects on growth, survival, and body composition. However, white bass fed an all-plant diet or a diet containing a proprietary protein blended fish meal replacement product had reduced growth so further refinements are necessary for these diet formulations to be able to be fed to this species. It appears that diet intake was the primary reason for the growth differences seen during the study, not essential amino acid (EAA) content, and that further research on the use of palatability enhancers for white bass may be prudent. No dietary formulation evaluated resulted in body composition differences in white bass indicating that all diets could be fed to the species without detrimental compositional changes. Further research is required to improve consumption of an all-plant diet and a diet containing a protein blended product as total replacement of fish meal.

CRediT authorship contribution statement

We would like to thank the Editor and the reviewers for their valuable comments and hope that the revised manuscript is suitable for publication in your esteemed journal.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments

This research was supported by funds provided by USDA/ARS CRIS Project 6028–31630-009–00D and USDA/ARS CRIS Project 6028-31630-008-00D. The authors thank Sarah Bennett and Rebecca Furbeck for assistance in processing the feeds and H.J. Baker Bros., Tuscola, TX, USA for providing the Pro-Cision™ used in this research. Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

References

Akbari, A., Wu, J., 2015. An integrated method of isolating napin and cruciferin from defatted canola meal. LWT-Food Sci. Tech. 64, 308–315.

Anderson, A.D., Alam, M.S., Watanabe, W.O., Carroll, P.M., Wedegaerther, T.C., Dowd, M.K., 2016. Full replacement of menhaden fish meal protein by low-gossypol cottonseed flour protein in the diet of juvenile black sea bass *Centropristis striata*. Aquaculture 464, 618–628.

AOAC (Association of Analytical Chemists), 2015. Official Methods of Analysis of Official Analytical Chemists International. Arlington, VA, USA.

Barrows, F.T., Gaylord T.G., Sealey W., Rawles S.D., 2016. Database of nutrient digestibility's of traditional and novel feed ingredients for trout and hybrid striped bass. 〈https://www.ars.usda.gov/pacific-west-area/aberdeen-id/small-grains-and-potato-germplasm-research/docs/fish-ingredient-database/〉.

Boyd, C.E., 1979. Water quality in warmwater fish ponds. Auburn Univ. Agric. Exp. Station, Auburn, AL, USA.

Bu, X.-Y., Wang, Y.-Y., Chen, F.-Y., Tang, B.-B., Luo, C.-Z., Yang, Y., Ge, X.-P., Yang, Y.-H., 2018. An evaluation of replacing fishmeal with rapeseed meal in the diet of *Pseudobagras ussuriensis*: growth, feed utilization, nonspecific immunity, and growth-related gene expression. J. World Aquac. Soc. 49, 1068–1080.

Burel, C., Boujard, T., Kaushik, S.J., Boeuf, G., van der Geyten, S., Mol, K.A., Kuhn, E.R., Quinsac, A., Krouti, M., Ribaillier, D., 2000. Potential of plant-protein sources as fish meal substitutes in diets for turbot (*Psetta maxima*): growth, nutrient utilization and thyroid status. Aquaculture 188, 363–382.

Burel, C., Boujard, T., Kaushik, S.J., 2001. Effects of rapeseed meal glucosinolates on thyroid metabolism and feed utilization in rainbow trout. Gen. Comp. Endocrinol. 124, 343–358.

Candebat, C.L., Booth, M., Codabaccus, M.B., Pirozzi, I., 2020. Dietary methionine spares the requirement for taurine in juvenile Yellowtail Kingfish (*Seriola lalandi*). Aquaculture 522, 735090. https://doi.org/10.1016/j.aquaculture.2020.735090.

Castillo, S., Halligan, S., Gatlin III, D.M., 2015. Growth responses of juvenile red drum *Sciaenops ocellatus* to dietary phenylalanine and tyrosine can be used to calculate the total aromatic amino acid requirement. J. Nutr. 145, 2341–2346.

Chatzifotis, S., Polemitou, I., Divanach, P., Antonopoulou, E., 2008. Effect of dietary taurine supplementation on growth performance and bile salt activated lipase activity of common dentex, *Dentex dentex*, fed a fish meal/soy protein concentrate-based diet. Aquaculture 275, 201–208.

Cheng, Z., Ai, Q., Mai, K., Xu, W., Ma, H., Li, Y., Zhang, J., 2010. Effects of dietary canola meal on growth performance, digestion and metabolism of Japanese seabass, *Lateolabrax japonicus*. Aquaculture 3025, 102–108.

Cho, C.Y., Bayley, H.S., Slinger, S.J., 1974. Partial replacement of herring meal with soybean meal and other changes in diets for rainbow trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 31, 1525–1528.

Coyle, S.D., Tidwell, J.H., Webster, C.D., 2000. Response of largemouth bass *Micropterus salmoides* to dietary supplementation of lysine, methionine, and highly unsaturated fatty acids. J. World Aquac. Soc. 31 (1), 89–95.

da Silva, J.G., Oliva-Teles, A., 1998. Apparent digestibility coefficients of feedstuffs in seabass (*Dicentrarchus labrax*) juveniles. Aquat. Living Resour. 11, 187–192.

Dairiki, J.K., Dias, dos Santos, Cyrino, J.E.P, C.T., 2007. Lysine requirement of largemouth bass, *Micropterus salmoides*: A comp[arison of methods of analysis of dose-response trials data. J. Appl. Aquacult. 19 (4), 1–27.

Davies, S.J., McConnel, S., Bateson, R.I., 1990. Potential of rapeseed meal as an alternative protein source in complete diets for tilapia (*Oreochromis mossambicus*). Aquaculture 87, 145–154.

Dawson, M.R., Alam, M.S., Watanabe, W.O., Carroll, P.M., 2018. Evaluation of poultry by-product meal as an alternative to fish meal in the diet of juvenile black sea bass reared in a recirculating aquaculture system. N. Am. J. Aquac. 80, 74–87.

Dossou, S., Koshio, S., Ishikawa, M., Yokoyama, S., Dawood, M.A.O., El Basuini, M.F., El-Hais, A.M., Olivier, A., 2018. Effect of partial replacement of fish meal by fermented rapeseed meal on growth, immune response and oxidative condition of red sea bream juvenile. Pagrus Major. Aquac. 490, 228–235.

El-Sayed, A.F.M., 1998. Total replacement of fish meal with animal protein sources in Nile tilapia, *Oreochromis niloticus*, feeds. Aquac. Res. 29, 275–280.

Estruch, G., Collado, M.C., Penaranda, D.S., Vidal, A.T., Cerda, M.J., Martinez, G.P., Martinez-Llorens, S., 2015. Impact of fishmeal replacement in diets for gilthead sea bream (*Sparus aurata*) on the gastrointestinal microbiota determined by pyrosequencing the 16S rRNA gene. PLoSOne 10, e0136389. https://doi.org/10.1371/journal.pone.0136389.

Francis, G., Makkar, H.P.S., Becker, K., 2001. Antinutritional factors present in plant-derived alternative fish feed ingredients and their effects in fish. Aquaculture 199, 197–227.

Garling, D.L., Wilson, R.P., 1977. Effect of dietary carbohydrate on growth and body composition of fingerling channel catfish. Prog. Fish. -Cult. 39, 43–47.

Gaylord, T.G., Rawles, S.D., Gatlin III, D.M., 2004. Amino acid availability from animal, blended, and plant feedstuffs for hybrid striped bass (*Morone chrysops x M. saxatilis*). Aquac. Nutr. 10, 345–352.

Glencross, B., Hawkins, W., Curnow, J., 2004. Nutritional assessment of Australian canola meals. I. Evaluation of canola oil extraction method and meal processing conditions on the digestible value of canola meals fed to the red seabream (*Pagrus auratus*, Paulin). Aquac. Res. 35, 15–24.

Gonzalez-Rodriguez, A., Celada, J.D., Carral, J.M., Saez-Royuela, M., Garcia, V., Fuertes, J.B., 2016. Evaluation of poultry by-product meal as partial replacement of fish meal in practical diets for juvenile tench (*Tinca tinca*). Aquac. Res. 47, 1612–1621.

Higgs, D.A., McBride, J.R., Markert, J.R., Dosanjh, B.S., Plotnikoff, M.D., Clarke, W.C., 1982. Evaluation of Tower and Candle rapeseed (canola) meal and Bronowski rapeseed protein concentrate as protein supplements in practical dry diets for juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Aquaculture 29, 1–31.

Karapanagiotidis, I.T., Psofakis, P., Mente, E., Malandrakis, E., Golomazou, E., 2019. Effect of fishmeal replacement by poultry by-product meal on growth performance, proximate composition, digestive enzyme activity, haematological parameters and gene expression of gilthead seabream (*Sparus aurata*). Aquac. Nutr. 25, 3–14.

Kaushik, S.J., 2002. European sea bass, *Dicentrarchus labrax*. In: Webster, C.D., Lim, C.E. (Eds.), Nutrient Requirements and Feeding of Finfish for Aquaculture. CABI Publishing, Wallingford, UK, pp. 28–39.

Kim, S.K., Matsunari, H., Takeuchi, T., 2008. Comparison of taurine biosynthesis ability between juveniles of Japanese flounder and common carp. Amino Acids 35, 161–168.

Koch, J.F., Rawles, S.D., Webster, C.D., Cummins, V., Kobayashi, Y., Thompson, K.R., Gannam, A.L., Twibell, R.G., Hyde, N.M., 2016. Optimizing fish meal-free commercial diets for Nile tilapia, *Oreochromis niloticus*. Aquaculture 452, 357–366.

Kureshy, N., Davis, D.A., Arnold, C.R., 2000. Partial replacement of fish meal with meat-and-bone meal, flash-dried poultry by-product meal, and enzyme-digested poultry by-product meal in practical diets for juvenile red drum. N. Am. J. Aquac. 62, 266–272.

Le Boucher, R., Vandeputte, M., Dupont-Nivet, M., Quillet, E., Ruelle, F., Vergnet, A., Kaushik, S., Allamellou, J.M., Medale, F., Chatain, B., 2014. Genotype by diet interactions in European sea bass (*Dicentrarchus labrax*): Nutritional challenge with totally plant-based diets. J. Anim. Sci. 91, 44–56.

Lim, C., Klesius, P.H., Higgs, D.A., 1998. Substitution of canola meal for soybean meal in diets for channel catfish *Ictalurus punctatus*. J. World Aquac. Soc. 29, 161–168.

Liu, X., Chi, S., Li, S., Cheng, X., Gao, W., Xu, Q., Zhang, W., Zhou, X., 2020. Substitution of fish meal with enzyme-treated soybean in diets for juvenile largemouth bass (*Micropterus salmoides*). Aquac. Nutr. 27, 1569–1577.

Luo, Y., Ai, Q., Mai, K., Zhang, W., Yu, W., Zhang, Y., 2012. Effects of dietary rapeseed meal on growth performance, digestion and protein metabolism in relation to gene expression of juvenile cobia (*Rachycentron canadum*). Aquaculture 368, 109–116.

Mazumber, A., Dwivedi, A., Plessis, J.D., 2016. Sinigrin and its therapeutic benefits. Molecules 21, 1–11.

McCann, K.M., Rawles, S.D., Lochmann, R.T., McEntire, M.E., Sealey, W.M., Gaylord, T. G., Webster, C.D., 2021. Dietary replacement of fishmeal with commercial protein blends designed for aquafeeeds in hybrid striped bass *(Morone chrysops x Morone saxatilis*): Digestibility, growth, body composition, and nutrient retention. Aquac. Rep. 21. https://doi.org/10.1016/j.aqrep.2021.100903.

Metts, L.S., Rawles, S.D., Brady, Y.J., Thompson, K.R., Gannam, A.L., Twibell, R.G., Webster, C.D., 2011. Amino acid availability from selected animal- and plant-derived feedstuffs for market-size sunshine bass (*Morone chrysops x Morone saxatilis*). Aquac. Nutr. 17, e123–e131. https://doi.org/10.1111/j.1365-2095.2009.00742.x.

Monge-Ortiz, R., Tomas-Vidal, A., Gallardo-Alvarez, F.J., Estruch, G., Godoy-Olmos, S., Jover-Cerda, M., Martinez-Llorens, S., 2018. Partial and total replacement of fishmeal by a blend of animal and plant proteins in diets for *Seriola dumerili*: Effects on performance and nutrient efficiency. Aquac. Nutr. 24, 1163–1174.

Muzinic, L.A., Thompson, K.R., Metts, L.S., Dasgupta, S., Webster, C.D., 2006. Use of turkey meal as partial and total replacement of fish meal in practical diets for sunshine bass (*Morone chrysops x Morone saxatilis*) grown in tanks. Aquac. Nutr. 12, 71–81.

Nengas, I., Alexis, M.N., Davies, S.J., 1999. High inclusion levels of poultry meals and related byproducts in diets for gilthead seabream *Sparus aurata*. Aquaculture 179, 13–23.

Ngo, D.T., Wade, N.M., Pirozzi, I., Glencross, B.D., 2016. Effects of canola meal on growth, feed utilization, plasma biochemistry, histology of digestive organs and hepatic gene expression of barramundi (Asian seabass; *Lates calcarifer*). Aquaculture 464, 95–105.

NRC, National Research Council, 2011. Nutrient Requirements Of Fish And Shrimp. National Academies Press, Washington, DC.

Pine, H.J., Daniels, W.H., Davis, D.A., Jiang, M., Webster, C.D., 2008. Replacement of fish meal with poultry by-product meal as a protein source in pond-raised sunshine bass, *Morone chrysops x M. saxatilis*, diets. J. World Aquac. Soc. 39, 586–597.

Portz, L., Cyrino, J.E.P., 2003. Comparison of the amino acid contents of roe, whole body and muscle tissue and their A/E ratios for largemouth bass *Micropterus salmoides* (Lacepede, 1802). Aquac. Res. 34, 585–592.

Portz, L., Cyrino, J.E.P., 2004. Digestibility of nutrients and amino acids of different protein sources in practical diets by largemouth bass *Micropterus salmoides* (Lacepede, 1802). Aquac. Res. 35, 312–320.

Portz, L., Cyrino, J.E.P., Martino, R.C., 2001. Growth and body composition of juvenile largemouth bass *Micropterus salmoides* in response to dietary protein and energy levels. Aquac. Nutr. 7, 247–254.

Rahman, M.M., Li, X., Sharifuzzaman, S.M., He, M., Poolsawat, L., Yang, H., Leng, X., 2021. Dietary threonine requirement of juvenile largemouth bass, *Micropterus salmoides*. Aquaculture 543 https://doi.org/10.1016j.aquaculture.2021.736884.

Ramena, Y., Rawles, S.D., Lochmann, R., Gaylord, T.G., McEntire, M.E., Farmer, B.D., Baumgartner, W., Webster, C.D., Beck, B.H., Green, B.W., Barnett, L.M., 2020. Growth, nutrient retention, innate immune response, and intestinal morphology of juvenile, soy-naïve hybrid striped bass, *Morone saxatilis x M. chrysops*, fed commercial-type, soy-based, ideal protein, fish meal replacement diets. Aquaculture 522, 735150. https://doi.org/10.1016/j.aquaculture.2020.735150.

Rawles, S.D., Gaylord, T.G., Gatlin III, D.M., 2006. Digestibility of nutrients by sunshine bass in animal by-products and commercially blended products used as fish meal replacements. N. Am. J. Aquac. 68, 74–80.

Rawles, S.D., Thompson, K.R., Brady, Y.J., Metts, L.S., Aksoy, M.Y., Gannam, A.L., Twibell, R.G., Ostrand, S., Webster, C.D., 2011. Effects of replacing fish meal with poultry by-product meal and soybean meal and reduced protein level on performance and immune status of pond-grown sunshine bass (*Morone chrysops x M. saxatilis*). Aquac. Nutr. 17, e708–e721. https://doi.org/10.1111/j.1365-2095.2010.00831.x.

Ren, X., Wang, Y., Chen, J.-M., Wu, Y.-B., Huang, D., Jiang, D.-L., Li, P., 2017. Replacement of fishmeal with a blend of poultry by-product meal and soybean meal in diets for largemouth bass, *Micropterus salmoides*. J. World Aquac. Soc. 49, 155–164.

Rossi, W., Davis, D.A., 2012. Replacement of fishmeal with poultry by-product meal in the diet of Florida pompano *Trachinotus carolinus*. Aquaculture 338–341, 160–166.

Rossi, W., Allen, K.M., Habte-tsion, H.-M., Meesala, K.M., 2021. Supplementation of glycine, prebiotic, and nucleotides in soybean meal-based diets for largemouth bass (*Micropterus salmoides*): Effects on production performance, whole-body nutrient composition and retention, and intestinal histopathology. Aquaculture 532, 736031. https://doi.org/10.1016/j.aquaculture.2020.736031.

Shapawi, R., Ng, W.K., Mustafa, S., 2007. Replacement of fish meal with poultry by-product meal in diets formulated for the humpback grouper, *Cromileptes altivaelis*. Aquaculture 273, 118–126.

Subhadra, B., Lochmann, R., Rawles, S., Chen, R., 2006. Effect of fish meal replacement with poultry by-product meal on the growth, tissue composition and hematological parameters on bass (*Micropterus salmoides*) fed diets containing different lipids. Aquaculture 260, 221–231.

Suehs, B., Gatlin, D.M., 2021. Evaluating the dietary taurine requirement of hybrid striped bass (*Morone chrysops x M. saxatilis*). Aquaculture 536, 736473. https://doi.org/10.1016/j.aquaculture.2021.736473.

Takagi, S., Murata, H., Goto, T., Endo, M., Yamashita, H., Ukawa, M., 2008. Taurine is an essential nutrient for yellowtail *Seriola quinquerdiata* fed non-fish meal diets based on soy protein concentrate. Aquaculture 280, 198–205.

Takagi, S., Murata, H., Goto, T., Hatate, H., Endo, M., Yamashita, H., Miyatake, H., Ukawa, M., 2010. Necessity of dietary taurine supplementation for preventing green liver symptom and improving growth performance in yearling red sea bream *Pagrus major* fed non-fish meal diets based on soy protein concentrate. Fish. Sci. 76, 119–130.

Takakuwa, F., Fukada, H., Hosokawa, H., Masumoto, T., 2006. Availability of poultry by-product meal as an alternative protein source for fish meal in diet for greater amberjack (*Seriola dumerili*). Aquac. Sci 54, 473–480.

Thompson, K.R., Metts, L.S., Muzinic, L.A., Dasgupta, S., Webster, C.D., 2007. Use of turkey meal as a replacement for menhaden fish meal in practical diets for sunshine bass grown in cages. N. Am. J. Aquac. 69, 351–359.

Thompson, K.R., Velasquez, A., Patterson, J.T., Metts, L.S., Webster, C.D., Brady, Y.J., Gannam, A.L., Twibell, R.G., Ostrand, S.L., 2012. Evaluation of plant and animal protein sources as partial or total replacement of fish meal in diets for Nile tilapia fry and juvenile stages. N. Am. J. Aquac. 74, 365–375.

Tidwell, J.H., Webster, C.D., Coyle, S.D., 1996. Effects of dietary protein level on second year growth and water quality for largemouth bass (*Micropterus salmoides*) raised in ponds. Aquaculture 145, 213–223.

Tidwell, J.H., Coyle, S.D., Bright, L.A., Yasharian, D., 2005. Evaluation of plant and animal source proteins for replacement of fish meal in practical diets for the largemouth bass *Micropterus salmoides*. J. World Aquac. Soc. 36, 454–463.

Wang, J., Clark, G., Min, J., Castillo, S., Gatlin III, D.M., 2020. Effects of replacing menhaden fishmeal with cottonseed flour on growth performance, feed utilization and body composition of juvenile red drum *Sciaenops ocellatus*. Aquaculture 523, 735217. https://doi.org/10.1016/j.aquaculture.2020.735217.

Wang, Y., Wang, F., Ji, W.-X., Han, H., Li, P., 2015. Optimizing dietary protein sources for Japanese sea bass (*Lateolabrax japonicus*) with an emphasis on using poultry by-product meal to substitute fish meal. Aquac. Res. 46, 874–883.

Watson, A.M., Buentello, A., Place, A.R., 2014. Partial replacement of fishmeal, poultry by-product meal and soy protein concentrate with two non-genetically modified soybean cultivars in diets for juvenile cobia, *Rachycentron canadum*. Aquaculture 434, 129–136.

Webster, C.D., Tidwell, J.H., Goodgame, L.S., Yancey, D.H., Mackey, L., 1992. Use of soybean meal and distillers grains with solubles as partial or total replacement of fish meal in diets for channel catfish, *Ictalurus punctatus*. Aquaculture 106, 301–309.

Webster, C.D., Tiu, L.G., Tidwell, J.H., Grizzle, J.M., 1997a. Growth and body composition of channel catfish (*Ictalurus punctatus*) fed diets containing various percentages of canola meal. Aquaculture 150, 103–112.

Webster, C.D., Tiu, L.G., Tidwell, J.H., 1997b. Growth and body composition of juvenile hybrid bluegill *Lepomis cyanellus x L. macrochirus* fed practical diets containing various percentages of protein. J. World Aquac. Soc. 28 (3), 230–240.

Webster, C.D., Tiu, L.G., Morgan, A.M., Gannam, A., 1999. Effect of partial and total replacement of fish meal on growth and body composition of sunshine bass *Morone chrysops x M. saxatilis* fed practical diets. J. World Aquac. Soc. 30, 443–453.

Webster, C.D., Thompson, K.R., Morgan, A.M., Grisby, E.J., Gannam, A.L., 2000. Use of hempseed meal, poultry by-product meal, and canola meal in practical diets without fish meal for sunshine bass (*Morone chrysops x M. saxatilis*). Aquaculture 188, 299–309.

Webster, C.D., Rawles, S.D., Koch, J.F., Thompson, K.R., Kobayashi, Y., Gannam, A.L., Twibell, R.G., Hyde, N.M., 2016. Bio-Ag reutilization of distiller's dried grains with solubles (DDGS) as a substrate for black soldier fly larvae, *Hermetia illucens*, along with poultry by-product meal and soybean meal, as total replacement of fish meal in diets for Nile tilapia, *Oreochromis niloticus*. Aquac. Nutr. 22, 976–988.

Webster, C.D., Rawles, S.D., Kelly, A.M., Roy, L.A., Rosentrater, K., 2021. Juvenile bluegill (*Lepomis macrochirus*) can be fed diets without fish meal without adverse effects on growth, survival, diet utilization and body composition. Aquacult. Nutr. 27, 1144–1159.

Wu, Y., Han, H., Qin, J., Wang, Y., 2015. Replacement of fishmeal by soy protein concentrate with taurine supplementation in diets for golden pompano (*Trachinotus ovatus*). Aquac. Nutr. 21, 214–222.

Wu, Y., Ma, H., Wang, X., Ren, X., 2021. Taurine supplementation increases the potential of fishmeal replacement by soybean meal in diets for largemouth bass *Micropterus salmoides*. Aquacult. Nutr. 27, 691–699.

Wu, Y.B., Ran, X., Chai, X.J., Li, P., Wang, Y., 2018. Replacing fish meal with a blend of poultry by-product meal and feather meal in diets for giant croaker (*Nibea japonica*). Aquac. Nutr. 24, 1085–1091.

Yesilayer, N., Kaymak, I.E., 2020. Effect of partial replacement of dietary fishmeal by soybean meal with betaine attractant supplementation on growth performance and fatty acid profiles of juvenile rainbow trout (*Oncorhynchus mykiss*). Aquac. Res. 51, 1533–1541.

Zar, J.H., 1984. Biostatistical analysis, Prentice-Hall Englewood, Cliff, NJ:

Zhang, C., Rahimnejad, S., Wang, Y.R., Lu, K., Sung, K., Wang, L., Mai, K., 2018. Substituting fishmeal with soybean meal in diets for Japanese seabass (*Lateolabrax japonicus*): Effects on growth, digestive enzymes activity, gut histology, and expression of gut inflammatory and transporter genes. Aquaculture 483, 173–182.

Zhou, H., Chen, N., Qiu, X., Zhao, M., Jin, L., 2012. Arginine requirement and effect of arginine intake on immunity in largemouth bass, *Micropterus salmoides*. Aquacult. Nutr. 18, 107–116.

Zhou, Q.-C., Zhao, J., Li, P., Wang, H.L., Wang, L.G., 2011. Evaluation of poultry by-product meal in commercial diets for juvenile cobia (*Rachycentron canadum*). Aquaculture 322–323, 122–127.