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Rearing Performance of Juvenile Brown Trout (*Salmo trutta*) Subjected to Exercise and Dietary Bioprocessed Soybean Meal

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Abstract

This 121-day experiment evaluated the rearing performance of brown trout *Salmo trutta* fed one of two isonitrogenous and isocaloric diets and reared at velocities of either 2.8 or 16.1 cm/s. Fishmeal was the primary protein source for the reference diet, and bioprocessed soybean meal replaced approximately 67% of the fishmeal in the experimental diet. At the end of the experiment, there were no significant differences in gain, percent gain, feed conversion rates, or specific growth rates between the dietary treatments. There were also no significant differences in intestinal morphology, splenosomatic, hepatosomatic, and viscerosomatic indices related to diet composition. However, gain, percent gain, feed fed, and specific growth rate were all significantly greater in brown trout reared at the higher velocity. No significant differences in any of the other variables measured were observed between the velocity treatments. There were no significant interactions between diet and velocity in any of the variables. Based on the results of this study, bioprocessed soybean meal can replace at least 67% of the fishmeal in brown trout diets, regardless of the rearing velocities used in this study. However, higher rearing velocities are recommended to maximize juvenile brown trout growth rates.

Keywords

Brown Trout, *Salmo trutta*, Bioprocessed Soybean Meal, Exercise, Diet

1. Introduction

With global human population expected to grow to 9 billion by 2050 [1], there is a need for increased and sustainable protein sources. Aquaculture production is rising to meet this demand, with the growth of aquaculture outpacing human population growth in the past five decades [1]. However, the continuing growth of aquaculture is constrained by the cost and unpredictability of aquatic animal feedstuffs [1].

Fishmeal, primarily produced from marine pelagic fish [1] [2], has historically been the primary protein ingredient in carnivorous fish [3] [4] [5]. However, nearly 90% of the world marine fisheries are fully-fished or overfished [1], and fishmeal risks becoming a limiting factor in aquaculture production. Thus, there is a need for sustainable proteins in aquafeed.

One of the leading plant-derived alternatives to dietary fishmeal is soybeans (*Glycine max*) [6] [7], due to its relative low cost and worldwide availability [8]. Soybean products are highly palatable [9] [10] [11], have a high protein content (~48% crude protein), and also have a balanced amino acid profile [12] [13]. However, there are antinutritional factors associated with soybean which hinder fish digestion [13] [14] [15] [16], and can also cause gastro-intestinal issues, such as enteritis [10] [17] [18] [19] [20]. Soybean products also have large concentrations of non-digestible carbohydrates [12] [21]. These factors limit the inclusion levels of soybean products in diets for carnivorous fish species [13] [22] [23] [24]. However, some of these antinutritional factors are decreased or inactivated by heat, which occurs during the feed extrusion process [14] [25] [26]. Bioprocessing, such as fermentation, has also been shown to eliminate or reduce antinutritional factors [27] [28].

Studies have examined bioprocessed soybean meal (BSM) in Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*) diets. However, there is limited research examining BSM in the diets of brown trout (*Salmo trutta*). Only one study has been published that evaluated fermented soybean products in brown trout diets. Sotoudeh *et al.* [29] replaced fishmeal with different forms of processed soybean meal (untreated, gamma-ray, irradiated, and fermented) and found that brown trout fed fermented soybean meal grew larger than fish on the non-fermented soybean meal diet. However, this study did not have a fishmeal reference diet, making results difficult to compare.

In addition to dietary influences on fish rearing performance, exercise can also impact rearing performance [30] [31] [32] [33]. Exercise (increased velocities and forced swimming) has been shown to improve growth of rainbow trout and Atlantic salmon fed to satiation [31] [34]. If feed is limited however, growth can be impaired at higher velocities [30]. Davison and Goldspink [35] examined the effect of prolonged swimming on brown trout, and found that intermediate speeds (1.5 and 3.0 body lengths/second; bl/s) resulted in greater growth than controls, but this study was very short (less than 30 days).

With only one uncontrolled study investigating BSM in brown trout diets, and only one study, of very limited duration, evaluating exercise during brown trout rearing, the need for further research is evident. More specifically, no research has been done to show the impacts velocity can possibly have on fish fed a BSM diet. Thus, the objective of this study was to examine the effects of both a diet with BSM as the primary protein source and velocity on the rearing performance and gastro-intestinal health of brown trout.

2. Methods

This experiment was conducted at McNenny State Fish Hatchery, Spearfish, South Dakota, USA, using degassed and aerated well water at a constant temperature of 11˚C (total hardness as $CaCO_3$, 360 mg/L; alkalinity as $CaCO_3$, 210 mg/L; pH, 7.6; total dissolved solids, 390 mg/L).

One-hundred twenty-eight Plymouth strain brown trout (initial weight 55.6 ± 1.5 g, length 166.2 ± 1.3 mm, mean ± SE) were randomly selected and placed into one of 16 circular fiberglass tanks (1.8 m diameter, 0.6 m depth) on September 15, 2016, at eight fish per tank. This 121-day study used a 2 × 2 design to evaluate the effects of water velocity and diet on brown trout rearing performance, with four tanks per treatment. Study design and water velocities used are described in Table 1.

Water velocities were recorded using a flowmeter (Flowatch, JDC Electronic SA, Yverdon-les-Bains, Jura-Nord Vaudois, Vaud, Switzerland) with readings taken directly behind the spray bar, 30.5 cm from the side of the tank and about 0.3 m deep (half way in water column). Flow rates were set and kept constant throughout the study.

Two different diets were used (Table 2), with modified soybean meal replacing 0% or 60% of the fishmeal as the primary protein source. The modified soybean meal was produced using a proprietary microbial conversion process (SDSU, Brookings, SD, USA). Diets were isocaloric and isonitrogenous and were manufactured by cooking extrusion (ExtruTech model 325, Sabetha, KS). Feed was analyzed according to AOAC [36] method 2001.11 for protein, 2003.5 (modified by substituting petroleum ether for diethyl ether) for crude lipid, and AACC [37] method 08 - 03 for ash content.

At the start of the experiment fish were individually weighed to the nearest 0.1 g, measured to the nearest 1.0 mm, and then placed into one of the sixteen tanks. Fish were weighed and measured approximately every four weeks. The individual fish weights were combined to obtain a total tank weight. Weight gain, percent

Table 1. Study design for dietary and velocity treatments, and mean velocities (±SE).

		Diet (% BSM)		Velocity		Velocity (cm/s)
Treatment	N	1 (0)	2 (60)	Low	High	
1	4	X		X		2.8 ± 0.4
2	4	X			X	16.1 ± 1.0
3	4		X	X		2.8 ± 0.4
4	4		X		X	16.1 ± 1.0

Table 2. Diet formulation and composition analyses of the diets used in the 121-day trial. Analysis conducted on post-extruded feed pellets.

	Diet (%)	
Ingredients	1	2
Fishmeal[a]	35.3	14.0
Bioprocessed soybean meal[b]	0.0	21.0
Wheat midds[c]	7.9	7.2
Whole wheat[c]	16.4	13.7
Poultry byproduct meal[d]	21.9	19.9
Blood meal[e]	2.6	2.5
Feather meal[d]	1.2	1.2
Vitamin premix[f]	0.8	2.0
Mineral premix[f]	0.8	2.0
Micro-mineral premix[f]	0.0	0.8
Choline chloride[g]	0.0	0.7
L-Lysine[h]	1.2	1.7
L-Methionine[i]	0.0	0.5
Stay-C 35[j]	0.0	0.3
Fish oil[k]	10.1	12.0
Total	100.0	100.0
Chemical analysis (% dry basis)		
Protein	46.98	45.76
Lipid	16.97	16.25
Ash	11.4	9.71
Nitrogen-free extract	18.79	20.63
Dry matter	96.48	95.85
Gross Energy (kJ/g)	17.8	17.2
Protein: Energy (MJ/g)	26.4	26.6

a. Special Select, Omega Protein, Houston, TX; b. SDSU; c. Consumer Supply, Sioux City, IA; d. Tyson Foods, Springdale, AR; e. Mason City Byproducts, Mason City, IAf NutraBlend, Neosho, MO; g. Balchem, New Hampton, NY; h. CJ Bio America, Fort Dodge, IA; i. Adisseo USA, Alpharreta, GA; j. DSM Nutritional Products, Ames, IA; k. Virginia Prime Gold, Omega Protein, Houston, TX.

gain, feed conversion ratio (FCR), and specific growth rate (SGR) were calculated. Individual fish weights and lengths were used to calculate Fulton's condition factor (K).

Fish were fed daily for 121 days, except on the days they were weighed and measured (days 35, 61, 92, and 121). Feeding amounts were initially determined by the hatchery constant method [38], with planned feed conversion rates of 1.1 and maximum growth rate of 0.07 cm/day, which was based on historical maximum growth rate of Plymouth strain brown trout at McNenny State Fish Hatchery [39]. Fish were fed by hand daily and feed was adjusted daily to be at or near satiation. Feed and mortality were recorded daily.

To collect weight and length data on days 1, 35, 61, and 92, the fish were anesthetized using 60 mg/L MS-222 (Tricaine-S, tricaine methanesulfonate, Syndel USA, Ferndale, Washington). On day 121, at the end of the experiment, fish were euthanized using a lethal dose of 250 mg/L MS-222 [40]. In addition to weight and length measurements, fin lengths, to the nearest 1.0 mm, and spleen, liver, and visceral weights, to the nearest 1.0 mg, were recorded from three randomly selected brown trout per tank. Fin indices, hepatosomatic index (HSI) [41], splenosomatic index (SSI) [42], and viscerosomatic index (VSI) [42] were calculated.

The following equations were used:

$$\text{Gain} = \text{end weight} - \text{start weight}$$

$$\text{Percent gain}(\%) = \frac{\text{gain}}{\text{start weight}}$$

$$\text{FCR} = \frac{\text{food fed}}{\text{gain}}$$

$$\text{SGR} = 100 * \frac{\ln(\text{end weight}) - \ln(\text{start weight})}{\text{number of days}}$$

$$\text{K} = 10^5 * \frac{\text{fish weight}}{\text{fish length}^3}$$

$$\text{Fin indices} = \frac{\text{fin length}}{\text{fish length}}$$

$$\text{HSI}(\%) = 100 * \frac{\text{liver weight}}{\text{whole fish weight}}$$

$$\text{SSI}(\%) = 100 * \frac{\text{spleen weight}}{\text{whole fish weight}}$$

$$\text{VSI}(\%) = 100 * \frac{\text{visceral weight}}{\text{whole fish weight}}$$

A 2-mm wide section of the distal intestine was removed from three randomly-selected fish per tank to assess any possible soy-induced enteritis [43] [44] [45] [46]. After dissection, the intestinal tissue was immediately put into 10% buffered formalin, and stained with haematoxylin and eosin using standard histological techniques [47] [48]. Intestinal inflammation was assessed using an ordinal scoring system (**Table 3**) based on lamina propria thickness and cellularity, submucosal connective tissue width, and leukocyte distribution [49] [50] [51].

Data was analyzed using the SPSS (9.0) statistical analysis program (SPSS, Chicago Illinois), with significance predetermined at $P < 0.05$. Two-way analysis of variance (ANOVA) was conducted, and if treatments were significantly different, post hoc mean separation tests were performed using Tukey's HSD test.

3. Results

At the end of the experiment there were no significant differences in gain, percent gain, FCR, SGR, and percent mortality between the tanks of fish receiving

Table 3. Histological scoring system used on brown trout fed fishmeal or bioprocessed soybean meal diets [51, modified from 42, 93].

Score	Appearance
	Lamina propria of simple folds
1	Thin and delicate core of connective tissue in all simple folds.
2	Lamina propria slightly more distinct and robust in some of the folds.
3	Clear increase in lamina propria in most of simple folds.
4	Thick lamina propria in many folds.
5	Very thick lamina propria in many folds.
	Connective tissue between base of folds and stratum compactum
1	Very thin layer of connective tissue between base of folds and stratum compactum.
2	Slightly increased amount of connective tissue beneath some of mucosal folds.
3	Clear increase of connective tissue beneath most of the mucosal folds.
4	Thick layer of connective tissue beneath many folds.
5	Extremely thick layer of connective tissue beneath some of the folds.
	Vacuoles
1	Large vacuoles absent.
2	Very few large vacuoles present.
3	Increased number of large vacuoles.
4	Large vacuoles are numerous.
5	Large vacuoles are abundant in present in most epithelial cells.

the fishmeal or BSM diet (**Table 4**). Overall mean (±SE) FCRs were relatively high for both the tanks receiving the fishmeal reference diet (2.50 ± 0.14) and in the BSM diet (2.78 ± 0.29). Food fed was significantly different between diets, with the fishmeal diet tanks receiving 928 (±92) g of feed and the BSM diet tanks receiving 685 (±88) g.

There were no significant differences between gain, percent gain, FCR, and SGR during any of the rearing periods. However, the amount of food fed was significantly different in all rearing periods, with the tanks of fish receiving the fishmeal diet consistently receiving more food. In rearing period 1 (first 35 days) the FCR was negative for the fish in tanks receiving the fishmeal diet, indicating that the trout actually lost weight. However, in rearing period 4 (days 93 - 121) gain, percent gain, and SGR were all significantly higher in the tanks of fish fed the fishmeal diet. Mean (±SE) percent gain in this rearing period (4) was 19.9 (±1.2)% and 15.1 (±1.7)% for the tanks of fish fed fishmeal and BSM diets, respectively. FCR for rearing period 4 was not significantly different.

Individual fish weight, length, and condition factor were not significantly different between dietary treatments at the end of the study (**Table 5**). None of the fin indices (pectoral, pelvic, and dorsal), organismic indices (HSI, SSI, VSI), or gut histology scores were significantly different between diets. Representative

Table 4. Mean (±SE) gain, percent gain, food fed, feed conversion ratio (FCR[a]), specific growth rate (SGR[b]), and mortality of brown trout receiving one of two different diets containing fishmeal or bioprocessed soybean meal (BSM) as the main protein ingredient, and reared at two different velocities. Overall means with different letters in same column or row differ significantly ($P < 0.05$). The absence of letters indicates no significant difference.

		Diet (% BSM)		
	Velocity	1 (0)	2 (60)	Overall
Initial				
	Low	489.6 ± 20.1	435.2 ± 15.0	462.4 ± 15.5
Start weight (g)	High	444.4 ± 36.3	409.1 ± 28.1	426.7 ± 22.3
	Overall	467.0 ± 21.0	422.1 ± 15.6	
Days 1 - 35				
	Low	511.6 ± 16.4	458.6 ± 21.4	485.1 ± 16.0
End weight (g)	High	516.9 ± 47.6	504.2 ± 28.7	510.6 ± 25.8
	Overall	514.2 ± 23.3	481.4 ± 18.7	
	Low	22.0 ± 10.4	23.4 ± 8.9	22.7 ± 6.4 y
Gain (g)	High	72.6 ± 12.1	95.1 ± 9.1	83.8 ± 8.2 z
	Overall	47.3 ± 12.1	59.3 ± 14.8	
	Low	4.7 ± 2.2	5.3 ± 2.0	5.0 ± 1.4 y
Gain (%)	High	16.0 ± 1.7	23.6 ± 3.1	19.8 ± 2.2 z
	Overall	10.3 ± 2.5	14.5 ± 3.9	
	Low	192 ± 5	144 ± 8	168 ± 10 y
Food fed (g)	High	284 ± 6	252 ± 22	268 ± 12 z
	Overall	238 ± 18 z	198 ± 23 y	
	Low	−21.83 ± 30.30	11.03 ± 4.75	-5.40 ± 15.50
FCR	High	4.27 ± 0.73	2.73 ± 0.34	3.50 ± 0.47
	Overall	−8.78 ± 14.87	6.88 ± 2.71	
	Low	0.13 ± 0.06	0.15 ± 0.06	0.14 ± 0.04 y
SGR	High	0.44 ± 0.04	0.62 ± 0.07	0.53 ± 0.05 z
	Overall	0.28 ± 0.07	0.39 ± 0.10	
Days 36 - 61				
	Low	533.2 ± 16.1	499.4 ± 34.3	526.3 ± 20.3
End weight (g)	High	602.1 ± 60.9	557.3 ± 36.8	579.7 ± 34.0
	Overall	577.6 ± 30.6	528.4 ± 25.7	
	Low	41.7 ± 6.6	40.8 ± 14.6	41.3 ± 7.4 y
Gain (g)	High	85.1 ± 13.7	53.1 ± 11.3	69.1 ± 10.2 z
	Overall	63.4 ± 10.8	47.0 ± 8.8	
	Low	8.2 ± 1.4	8.6 ± 2.7	8.4 ± 1.4 y
Gain (%)	High	16.2 ± 1.4	10.4 ± 2.0	13.3 ± 1.6 z
	Overall	12.2 ± 1.8	9.5 ± 1.6	
	Low	112 ± 6	81 ± 17	97 ± 10 y
Food fed (g)	High	176 ± 13	146 ± 11	161 ± 10 z
	Overall	144 ± 14 y	114 ± 15 z	

Continued

	Low	2.85 ± 0.33	2.96 ± 1.16	2.90 ± 0.56
FCR	High	2.27 ± 0.49	3.16 ± 0.73	2.72 ± 0.44
	Overall	2.56 ± 0.30	3.06 ± 0.64	
	Low	0.29 ± 0.05	0.30 ± 0.09	0.30 ± 0.05 y
SGR	High	0.55 ± 0.04	0.36 ± 0.07	0.56 ± 0.05 z
	Overall	0.42 ± 0.06	0.33 ± 0.06	
Days 62 - 92				
	Low	669.2 ± 32.6	565.5 ± 67.8	617.3 ± 39.9
End weight (g)	High	738.3 ± 69.8	645.9 ± 51.3	692.1 ± 43.8
	Overall	703.7 ± 38.0	605.7 ± 42.2	
	Low	115.9 ± 24.3	66.0 ± 33.6	91.0 ± 21.4
Gain (g)	High	136.2 ± 17.6	88.6 ± 16.7	112.4 ± 14.4
	Overall	126.1 ± 14.4	77.3 ± 17.9	
	Low	20.9 ± 4.4	12.1 ± 5.4	16.5 ± 3.6
Gain (%)	High	23.1 ± 3.5	15.6 ± 2.2	19.4 ± 2.4
	Overall	22.0 ± 2.6	13.9 ± 2.8	
	Low	197 ± 26	133 ± 33	165 ± 23 y
Food fed (g)	High	311 ± 51	226 ± 29	269 ± 31 z
	Overall	254 ± 34	180 ± 27	
	Low	1.83 ± 0.22	3.18 ± 0.96	2.50 ± 0.52
FCR	High	2.28 ± 0.19	2.64 ± 0.16	2.46 ± 0.13
	Overall	2.05 ± 0.16	2.91 ± 0.46	
	Low	0.61 ± 0.12	0.36 ± 0.15	0.48 ± 0.10
SGR	High	0.67 ± 0.09	0.47 ± 0.06	0.57 ± 0.06
	Overall	0.64 ± 0.07	0.41 ± 0.08	
Days 93 - 121				
	Low	794.2 ± 47.0	650.6 ± 90.1	722.4 ± 56.4
End weight (g)	High	896.3 ± 49.4	752.1 ± 67.2	824.2 ± 57.5
	Overall	845.2 ± 49.4	701.3 ± 57.6	
	Low	125.0 ± 15.7	85.1 ± 28.7	105.0 ± 16.9
Gain (g)	High	158.0 ± 19.0	106.2 ± 17.1	132.2 ± 15.4
	Overall	141.5 ± 13.0 z	95.7 ± 16.0 y	
	Low	18.5 ± 1.7	14.0 ± 3.1	16.3 ± 1.9
Gain (%)	High	21.4 ± 1.7	16.2 ± 1.7	18.8 ± 1.5
	Overall	19.9 ± 1.2 z	15.1 ± 1.7 y	
	Low	229 ± 31	144 ± 32.4	187 ± 26 y
Food fed (g)	High	355 ± 36	245 ± 31	300 ± 30 z
	Overall	292 ± 32 z	195 ± 28 y	
	Low	1.83 ± 0.04	1.90 ± 0.21	1.86 ± 0.10 y
FCR	High	2.28 ± 0.15	2.36 ± 0.19	2.32 ± 0.11 z
	Overall	2.05 ± 0.11	2.13 ± 0.16	
	Low	0.58 ± 0.05	0.45 ± 0.10	0.52 ± 0.06
SGR	High	0.67 ± 0.05	0.52 ± 0.05	0.59 ± 0.04
	Overall	0.63 ± 0.04 z	0.48 ± 0.05 y	

Continued

Overall (Days 1 - 121)				
	Low	304.6 ± 40.3	215.4 ± 82.6	260.0 ± 45.8 y
Gain (g)	High	452.0 ± 53.0	343.0 ± 45.1	397.5 ± 38.2 z
	Overall	378.3 ± 41.5	279.2 ± 49.8	
	Low	62.4 ± 8.8	48.0 ± 16.7	55.2 ± 9.2 y
Gain (%)	High	101.4 ± 6.6	83.6 ± 8.6	92.5 ± 6.0 z
	Overall	81.9 ± 9.0	65.8 ± 11.0	
	Low	730 ± 61	502 ± 87	616 ± 65 y
Food fed (g)	High	1,127 ± 96	868 ± 81	998 ± 76 z
	Overall	928 ± 92 z	685 ± 88 y	
	Low	2.45 ± 0.15	2.98 ± 0.59	2.72 ± 0.30
FCR	High	2.55 ± 0.26	2.58 ± 0.13	2.56 ± 0.13
	Overall	2.50 ± 0.14	2.78 ± 0.29	
	Low	0.40 ± 0.04	0.31 ± 0.09	0.35 ± 0.05 y
SGR	High	0.58 ± 0.03	0.50 ± 0.04	0.54 ± 0.03 z
	Overall	0.49 ± 0.04	0.40 ± 0.06	
	Low	12.5 ± 5.1	25.0 ± 8.8	18.8 ± 5.3 y
Mortality (%)	High	0.0 ± 0.0	9.4 ± 6.0	4.7 ± 3.3 z
	Overall	6.2 ± 3.3	17.2 ± 5.8	

a. FCR = feed conversion ratio = total food fed/total weight gain; b. SGR = 100 × [(ln(final weight) − ln(initial weight))/days].

Table 5. Mean (±SE) condition factor (K[a]), fin indices[b], hepatosomatic index (HSI[c]), splenosomatic index (SSI[d]), viscerosomatic index (VSI[e]), and histology scores for lamina propria, connective tissue, and vacuoles of brown trout receiving one of two different diets containing fishmeal or bioprocessed soybean meal (BSM) as the main protein ingredient, and reared at two different velocities. Overall means with different letters in same column or row differ significantly ($P < 0.05$). The absence of letters indicates no significant difference.

		Diet (% BSM)		
	Velocity	1 (0)	2 (60)	Overall
Initial				
	Low	61.2 ± 2.5	54.4 ± 1.9	57.8 ± 1.9
Weight (g)	High	55.5 ± 4.5	51.1 ± 3.5	53.3 ± 2.8
	Overall	58.4 ± 2.6	52.8 ± 1.9	
	Low	171.9 ± 1.9	164.3 ± 1.9	168.1 ± 1.9
Length (mm)	High	166.3 ± 4.4	162.3 ± 2.8	164.3 ± 2.5
	Overall	169.1 ± 2.5	163.3 ± 1.6	
	Low	1.19 ± 0.02	1.19 ± 0.01	1.19 ± 0.01
K	High	1.18 ± 0.02	1.15 ± 0.02	1.16 ± 0.01
	Overall	1.18 ± 0.01	1.17 ± 0.01	

Continued

Days 1 - 35					
		Low	63.9 ± 2.1	57.3 ± 2.7	60.6 ± 2.0
	End weight (g)	High	64.6 ± 6.0	63.0 ± 3.6	63.8 ± 3.2
		Overall	64.3 ± 2.9	60.2 ± 2.3	
		Low	178.2 ± 1.4	168.2 ± 3.1	173.2 ± 2.5
	End length (mm)	High	175.2 ± 4.6	172.6 ± 2.6	173.9 ± 2.5
		Overall	176.7 ± 2.3	170.4 ± 2.1	
		Low	1.12 ± 0.03	1.17 ± 0.03	1.15 ± 0.02
	K	High	1.16 ± 0.02	1.17 ± 0.03	1.17 ± 0.02
		Overall	1.14 ± 0.01	1.17 ± 0.02	
Days 36 - 61					
		Low	70.1 ± 3.0	66.5 ± 2.8	68.3 ± 2.0
	End weight (g)	High	75.3 ± 7.6	69.7 ± 4.6	72.5 ± 4.2
		Overall	72.7 ± 3.9	68.1 ± 2.6	
		Low	185.3 ± 2.4	178.2 ± 2.6	181.8 ± 2.1
	End length (mm)	High	185.3 ± 5.1	180.5 ± 3.1	182.9 ± 2.9
		Overall	185.3 ± 2.6	179.4 ± 1.9	
		Low	1.10 ± 0.03	1.14 ± 0.01	1.12 ± 0.02
	K	High	1.14 ± 0.02	1.15 ± 0.02	1.15 ± 0.02
		Overall	1.12 ± 0.02	1.15 ± 0.01	
Days 62 - 92					
		Low	86.2 ± 5.5	77.1 ± 6.1	81.6 ± 4.2
	End weight (g)	High	92.3 ± 8.7	80.8 ± 6.4	86.5 ± 5.5
		Overall	89.2 ± 4.9	78.9 ± 4.2	
		Low	195.8 ± 3.3	187.1 ± 4.2	191.4 ± 3.0
	End length (mm)	High	198.4 ± 5.2	190.4 ± 4.1	194.4 ± 3.4
		Overall	197.1 ± 2.9 z	188.7 ± 2.8 y	
		Low	1.13 ± 0.03	1.14 ± 0.01	1.14 ± 0.01
	K	High	1.14 ± 0.02	1.12 ± 0.02	1.13 ± 0.01
		Overall	1.14 ± 0.02	1.13 ± 0.01	

a. K = 105 × [weight/(length3)]; b. Fin indices = 100 × (fin length/fish length); c. HSI = 100 × (liver weight/body weight); d. SSI = 100 × (spleen weight/body weight); e. VSI = 100 × (visceral weight/body weight).

images of the distal intestines from fish fed each diet, and velocities used for the scoring are shown in **Figures 1-4**. The only significant differences observed in any of the individual fish data in any of the rearing periods occurred in rearing period 3 (day 62 - 92), where the mean (±SE) length of fish fed the fishmeal diet was 197.1 (±2.9) mm compared to 188.7 (±2.8) mm in the fish fed the bioprocessed soybean meal diet.

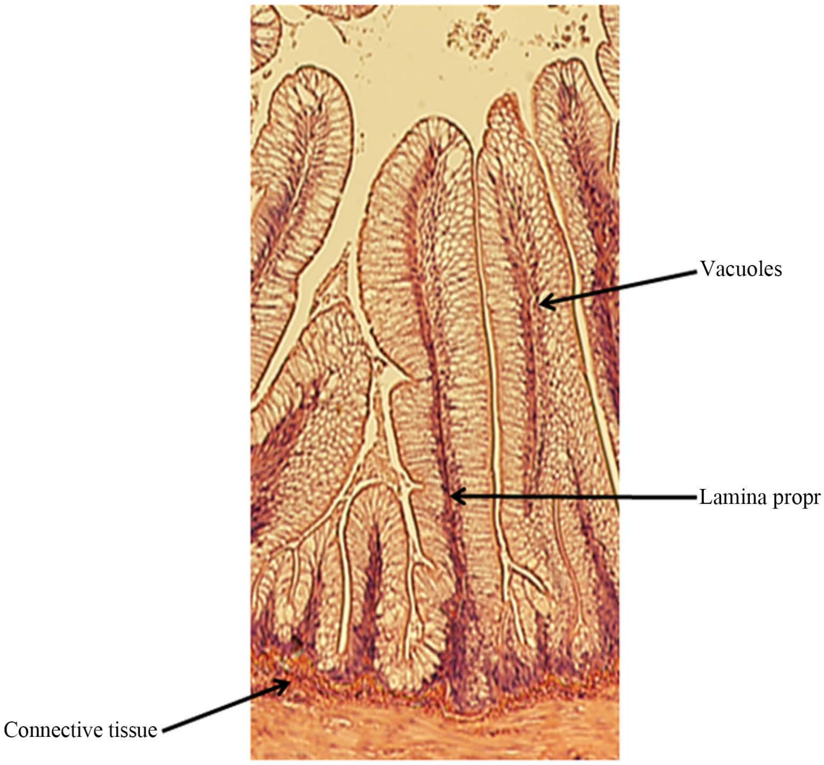

Figure 1. Distal intestine of brown trout receiving 0% bioprocessed soybean meal and reared at low velocity.

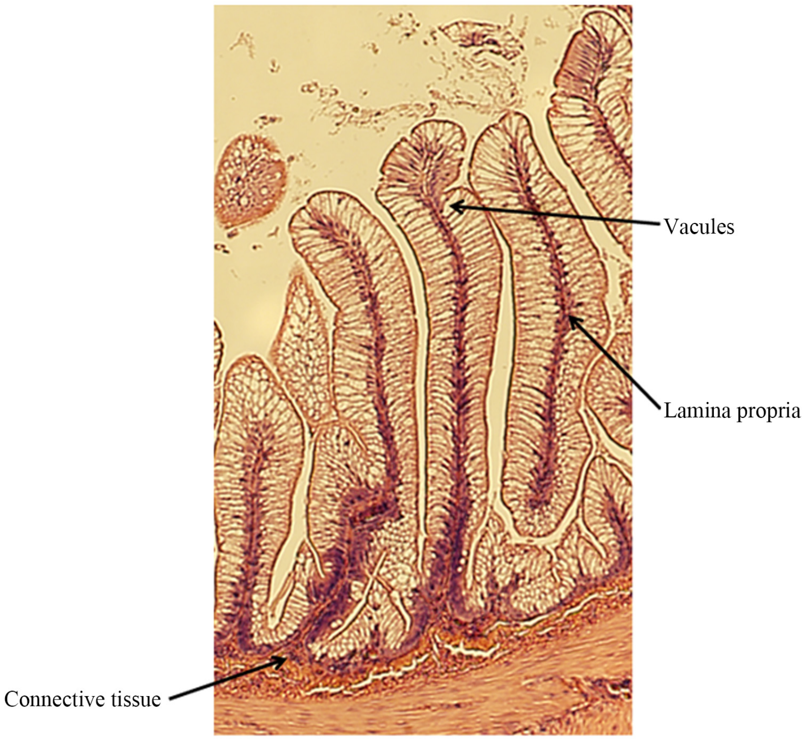

Figure 2. Distal intestine of brown trout receiving 0% bioprocessed soybean meal and reared at high velocity.

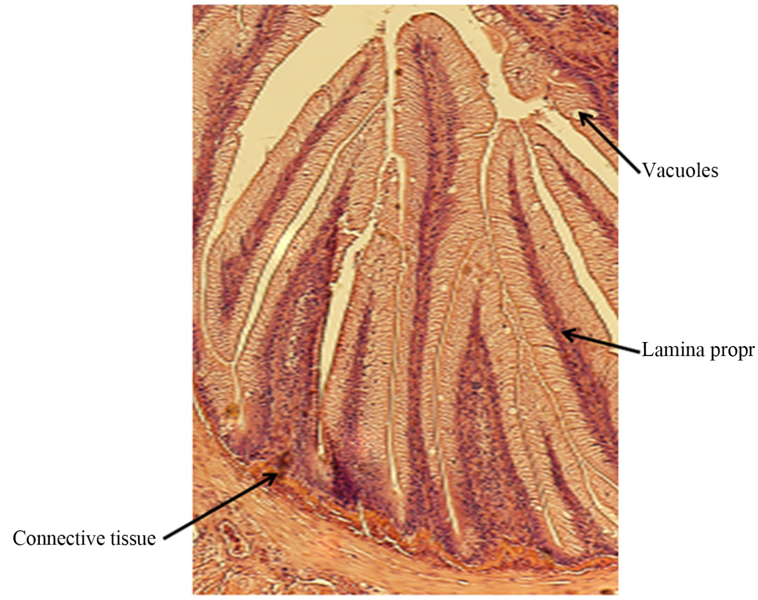

Figure 3. Distal intestine of brown trout receiving 60% bioprocessed soybean meal and reared at low velocity.

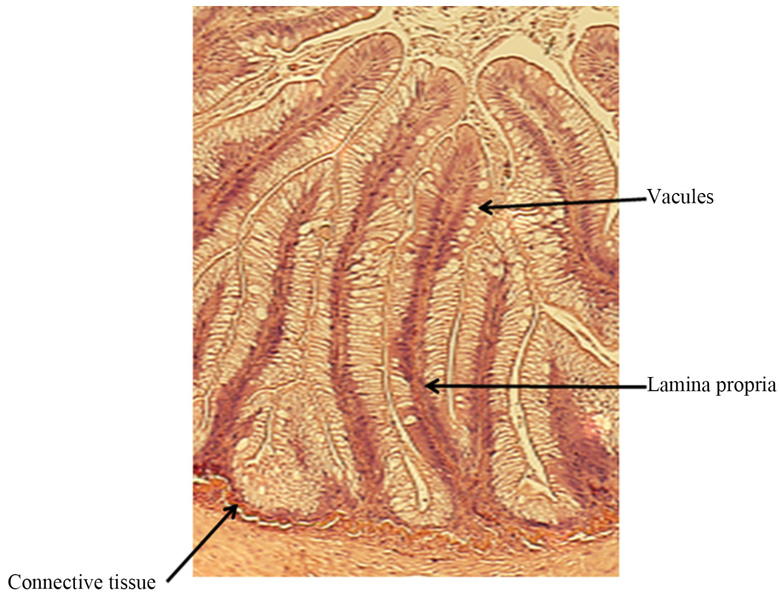

Figure 4. Distal intestine of brown trout receiving 60% bioprocessed soybean meal and reared at high velocity.

Several significant differences in brown trout rearing performance were observed between the two velocity treatments. Gain, percent gain, food fed, and SGR were significantly higher in the tanks of fish reared at higher velocity overall and in the first two rearing periods. Mean (±SE) percent gain was only 55.2 (±9.2)% in lower velocity tanks, but was 92.5 (±6.0)% in the higher velocity tanks. However, in the last two rearing periods there is no a significant differences in gain, percent gain, nor SGR. In addition, mean (±SE) percent mortality was significantly higher in the lower velocity tanks at 18.8 (±5.3)%, compared to 4.7 (±3.3)% in the higher velocity tanks. Overall mean (±SE) FCRs were not significantly different, but were relatively poor at 2.72 (±0.30) for the tanks of fish at the lower velocity and 2.56 (±0.13) for the tanks of fish at higher velocity.

The amount of food fed was significantly higher in the higher velocity tanks for all of the rearing periods. FCR was only significantly different in rearing period 4, where tanks of brown trout at the faster velocity had a higher mean (±SE) of 2.32 (±0.11) compared to 1.86 (±0.10) for the slower velocity tanks. Similar to the dietary results, mean (±SE) FCRs in both velocities were extremely poor and inconsistent in rearing period 1, with the tanks of fish at the lower velocity having a FCR of −5.40 (±15.50) compared to 3.50 (±0.47) in the higher velocity tanks. Gain, percent gain, and SGR were only significantly greater in the higher velocity treatment during the first two rearing periods.

At the end of the experiment, and in every rearing period, individual fish weight, length, and condition factor were not significantly differences between the velocity treatments. In addition, no significant differences in fin index scores, hepatosomatic index, splenosomatic index, viscerosomatic index, nor any of the histological scores were observed between the low and high velocity treatments. There were no interactions between diet and velocity in any of the variables measured at either the end of the study or at the end of any of the rearing periods.

4. Discussion

The similarity in rearing performance response between the two diets indicates that BSM can replace at least 67% of the fishmeal in brown trout diets. Sotoudeh *et al.* [29] also indicated the suitability of fermented soybean meal in brown trout diets. However, the Sotoudeh *et al.* [29] study had no fishmeal-based reference diet, making it difficult to compare their results to this study. The results from this experiment with brown trout are consistent with those reported in rainbow trout by Bruce *et al.* [52] [53] who replaced 65% of the dietary fishmeal with BSM with no observed ill-effects. In addition, Barnes *et al.* [51] [54] [55] replaced approximately 62% of the fishmeal with a commercial fermented soybean product without any significant difference in rainbow trout performance. Yamamoto *et al.* [56] [57] also reported positive results with fermented soybean meal in rainbow trout diets. Different forms of BSM have been evaluated in Atlantic salmon diets, but fishmeal replacement rates appeared limited to 20% or less [28]. Other species where fermented, or other forms of bioprocessed, soybean have been evaluated include Atlantic cod (*Gadus morhua*) [58] [59], black sea bream (*Acanthopagrus schlegeli*) [60] [61], Chinese sucker (*Myxocyprinus asiaticus*) [62], Florida pompano (*Trachniotus carolinus*) [46], gilthead sea bream (*Sparus aurata* L.) [63], Japanese flounder (*Paralichthys olivaceus*) [64], largemouth bass (*Micropterus salmoides*) [65], orange-spotted grouper (*Epinephelus coioides*) [66], whiteleg shrimp (*Litopenaeus vannamei*) [66] [67] [68], rockfish (*Sebastes schlegeli*) [69], white seabass (*Atractosion nobilis*) [70], and yellowtail jack (*Seriola lalandi*) [70].

There has been minimal research done on the long-term effects of soybean products in salmonid diets, with only a few experiments lasting over 100 days [19] [24] [51] [54] [71] [72] [73]. At 121 days, this study should have met the Weathercup and McCraken [74] criteria for being long enough to determine any differences in fish performance among the diets. This study also met the NRC [13] recommendation of lasting 56 - 84 days. However, even at 121 days, the brown trout only produced a 150% gain, short of the 200% gain recommended by NRC [13] for feeding trial durations. Interestingly, gain, percent gain, and specific growth rate did not differ significantly between the diets for the first three months, but significantly improved in fish fed the fishmeal diet during the final rearing period. This is consistent with de Francesco *et al.* [75], who did not see differences in rearing performance between fishmeal and plant-based diets until after 84 days. It is unknown if significant differences between the fishmeal and BSM would have occurred beyond the end of this experiment.

The poor initial growth rate and relatively poor FCRs throughout this experiment may be due to palatability problems. Poor palatability has been suggested to contribute to lower feed intake and reduced growth [52] [76]. Overall, FCRs from the brown trout in this study are higher (worse) than that reported by Regost *et al.* [77] or Kizak *et al.* [78]. However, Kizak *et al.* [78] fed a restricted ration, which has been shown to improve FCR [79]. The SGR at the beginning being of the experiment was approximately 0.3, but improved to approximately 0.55 at the final rearing period. This is similar to the 0.6 SGR reported for brown trout by Regost *et al.* [77].

It is unknown why the FCR was similar between the dietary treatments, despite the significant increase in feed consumption in fish fed the fishmeal diet. FCR is calculated by dividing the amount of food fed by the gain [80], and any significant increase in food fed, with no change in gain, should produce a corresponding increase in FCR. This enigma could be a statistical artifact, possibly due to small sample sizes [81].

Soybean products in the diets of salmonids have caused well-documented and potentially-deleterious effects in the distal intestine of rainbow trout [15] [72] [82] [83]. Intestinal microbial communities may also be affected [19] [53] [72] [84]. These issues have been reported in Atlantic salmon [85] [86] [87] [88], a species closely-related to brown trout. However, the histological data in this study did not indicate any enteritis in any of the fish receiving the BSM diet or in the fish receiving the fishmeal diet. Fermentation decreases antinutritional factors [54] [56] [57] [89], making it likely that the saponins [18] and possibly other gastro-inducing compounds were removed during bioprocessing. The histological scores observed in this study tended to be lower than those reported by Barnes *et al.* [51] [55] [90]. However, the Barnes' studies examined rainbow trout which were fed different diets than those used in this study. In addition, Bruce *et al.* [53] also used the same scoring system with rainbow trout but compiled and averaged all numbers for an overall histology score.

The lack of any differences in HSI between the dietary or velocity treatments indicates similar energy partitioning. HSI is an indirect measure of glycogen and carbohydrate levels, and can be used to indicate nutritional state of the fish [91] [92] [93]. The HSI of 1.1 to 1.2 found in this study is slightly higher than the brown trout HSI of 0.9 to 1.0 in Sotoudeh *et al.* [94], but lower for other studies (1.4 to 1.7) [29] [78] [95]. The comparably lower HSI values in this study may be due to different diets or may also be indicative of different stressors among the studies. Both HSI and VSI are used to indicate if energy is being diverted away from organ or tissue growth in order to combat stress, and this is indicated by lower indices [93].

VSI values indicate how lipids are being used and there is a positive relationship between lipid levels and VSI values [96] [97] [98]. Thus, similar VSI values among the dietary and velocity treatments are likely due to similar dietary lipid levels. While VSI values in this experiment were relatively low compared to Mambrini *et al.* [95], Sotoudeh *et al.* [94], and Kizak *et al.* [78], they were similar to those reported by Sotoudeh *et al.* [29], which is the only experiment examining processed soybean products in brown trout diets.

SSI indicates the hematopoietic capacity of fish [93] and antibody production mostly occurs in the spleen [99]. Similar SSI values indicate that fish health was unaffected by diet or velocity. No literature values for brown trout SSI could be found, but dietary experiments with rainbow trout SSI had similar values to those observed in the brown trout in this study [52] [55]. In two velocity studies that reported SSI in rainbow trout, SSI values were approximately 25% higher than those observed in this study [31] [100].

In addition to diet, exercise has been shown to impact fish growth [30] [31] [32] [33]. Higher velocities improved fish rearing performance in this study, but the positive effects were primarily limited to the first 8 weeks. Nearly all of the other studies investigating exercise have lasted between 4 and 10 weeks [30] [31] [32] [33] [35] [101] [102] [103] [104] [105]. Only one other velocity experiment has lasted 4 months, but growth data was not reported [106]. Why did the influence of exercise on growth rates and gain disappear after eight weeks? Perhaps the fish could be exhibiting exercise fatigue, which has been reported in humans after extended periods of intense exercise [107] [108] [109] [110].

As expected, fish at the higher velocity ate significantly more food then fish at the lower velocities. It is well documented that although more food must be consumed to meet the increased energy demands from exercise, feed efficiency will be the same or better at lower velocities [31] [111] [112] [113]. This was also observed in the present study where, similar to other studies [101] [105], the FCR was not significantly different in the overall data, or for the first three rearing periods. However, the final rearing period saw a significant difference in FCRs between the two velocities. The fish in lower velocity tanks converted better at a ratio of 1.86, while the higher velocity fish converted at 2.32. This could potentially be another indicator of exercise fatigue.

The lack of difference in the fin indices among the dietary or velocity treatments indicates dietary suitability, as well as a lack of environmental stress [114], adequate feeding rates [115], no nutritional differences [116] [117], and good fish health [118]. Fin erosion has been found to be due to several factors, including tank-induced abrasions [119], rearing unit size and type [120], aggressive behavior [114], feeding rates [115], rearing densities [121] [122] [123], and fish health [118]. Bosakowski and Wagner [120] is the only other paper that has examined fin indices for brown trout, which had relative pectoral and pelvic lengths approximately 30% less than observed in this study. However, the relative dorsal length reported by Bosakowski and Wagner [120] was over 35% greater than in this experiment.

5. Conclusion

In conclusion, BSM can replace fishmeal in brown trout diets with no ill-effects, even if the trout is subjected to exercise. In addition, regardless of diet, exercise improves fish rearing performance, at least initially. Additional research on complete fishmeal replacement with BSM in brown trout diets is needed. There is also a need to examine potential exercise fatigue in fish forced to swim continuously for extended periods of time.

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References

[1] Food and Agriculture Organization of the United Nations (FAO) (2016) The State of World Fisheries and Aquaculture 2016: Contributing to Food Security and Nutrition for All. Food and Agriculture Organization, Rome. http://www.fao.org/3/a-i5555e.pdf

[2] Food and Agriculture Organization of the United Nations (FAO) (2017) Fisheries and Aquaculture Statistics 2015. Food and Agriculture Organization, Rome. http://www.fao.org/documents/card/en/c/68440a7a-2adb-416d-872b-b233eb44f6c9/

[3] Satia, B.P. (1974) Quantitative Protein Requirements of Rainbow Trout. *The Progressive Fish-Culturist*, **36**, 80-85. https://doi.org/10.1577/1548-8659(1974)36[80:QPRORT]2.0.CO;2

[4] Kim, K.I., Kayes, T.B. and Amundson, C.H. (1991) Purified Diet Development and Reevaluation of the Dietary Protein Requirement of Fingerling Rainbow Trout. (*Oncorhynchus mykiss*). *Aquaculture*, **96**, 57-67. https://doi.org/10.1016/0044-8486(91)90139-X

[5] Cheng, Z.J. and Hardy, R.W. (2004) Nutritional Value of Diets Containing Distiller's Dried Grain with Solubles for Rainbow Trout, *Oncorhynchus mykiss*. *Journal of Applied Aquaculture*, **15**, 101-113. https://doi.org/10.1300/J028v15n03_08

[6] Nordrum, S., Bakke-McKellep, A.M., Krogdahl, Å. and Buddington, R.K. (2000)

Effects of Soybean Meal and Salinity on Intestinal Transport of Nutrients in Atlantic Salmon (*Salmo salar* L.) and Rainbow Trout (*Oncorhynchus mykiss*). *Comparative Biochemistry and Physiology Part B*: *Biochemistry and Molecular Biology*, **125**, 317-335. https://doi.org/10.1016/S0305-0491(99)00190-X

[7] Li, M.H. and Robinson, E.H. (2015) Complete Feeds—Intensive Systems. In: Davis, D.A., Ed., *Feed and Feeding Practices in Aquaculture*, Woodhead Publishing, Sawston, Waltham, 112-126. https://doi.org/10.1016/B978-0-08-100506-4.00004-0

[8] United States Department of Agriculture (USDA) (2017) Oilseeds: World Markets and Trade. United States Department of Agriculture, Ithaca. http://usda.mannlib.cornell.edu/usda/fas/oilseed-trade//2010s/2017/oilseed-trade-12-12-2017.pdf

[9] Sugiura, H.S., Dong, F.M., Rathbone, C.K. and Hardy, R.W. (1998) Apparent Protein Digestibility and Mineral Availabilities in Various Feed Ingredients for Salmonid Feeds. *Aquaculture*, **159**, 177-202. https://doi.org/10.1016/S0044-8486(97)00177-4

[10] Refstie, S., Korsoen, O.J., Storebakken, T., Baeverfjord, G., Lein, I. and Roem, A.J. (2000) Differing Nutritional Responses to Dietary Soybean Meal in Rainbow Trout (*Oncorhynchus mykiss*) and Atlantic Salmon (*Salmo salar*). *Aquaculture*, **190**, 49-63. https://doi.org/10.1016/S0044-8486(00)00382-3

[11] Watanabe, T. (2002) Strategies for Further Development of Aquatic Feeds. *Fisheries Science*, **68**, 242-252.

[12] Gatlin III, D.M., Barrows, F.T., Brown, P., Dabrowski, K., Gaylord, T.G., Hardy, R.W., Herman, E., Hu, G., Krogdahl, Å., Nelson, R., Overturf, K., Rust, M., Sealey, W., Skonberg, D., Souza, E.J., Stone, D., Wilson, R. and Wurtele, E. (2007) Expanding the Utilization of Sustainable Plant Products: A Review. *Aquaculture Research*, **38**, 551-579. https://doi.org/10.1111/j.1365-2109.2007.01704.x

[13] National Research Council (NRC) (2011) Nutrient Requirements of Fish and Shirmp. National Academy Press, Washington DC.

[14] Barrows, F.T., Stone, D.A.J. and Hardy, R.W. (2007) The Effects of Extrusion Conditions on the Nutritional Value of Soybean Meal for Rainbow Trout (*Oncorhynchus mykiss*). *Aquaculture*, **265**, 244-252. https://doi.org/10.1016/j.aquaculture.2007.01.017

[15] Iwashita, Y., Yamamoto, T., Furuita, H., Sugita, T. and Suzuki, N. (2008) Influence of Certain Soybean Antinutritional Factors Supplemented to a Casein-Based Semipurified Diet on Intestinal and Liver Morphology in Fingerling Rainbow Trout *Oncorhynchus mykiss*. *Fisheries Science*, **74**, 1075-1082. https://doi.org/10.1111/j.1444-2906.2008.01627.x

[16] Teng, D., Gao, M., Yang, Y., Liu, B., Tian, Z. and Wang, J. (2012) Bio-Modification of Soybean Meal with *Bacillus subtilis* or *Aspergillus oryzae*. *Biocatalysis and Agriculture Biotechnology*, **1**, 32-38. https://doi.org/10.1016/j.bcab.2011.08.005

[17] Krogdahl, A., Bakke-McKellep, A.M., Roed, K.H. and Baeverfjord, G. (2000) Feeding Atlantic Salmon (*Salmo salar* L.) Soybean Products: Effects on Disease Resistance (Furunculosis), and Lysozyme and IgM Levels in the Intestinal Mucosa. *Aquaculture Nutrition*, **6**, 77-84. https://doi.org/10.1046/j.1365-2095.2000.00129.x

[18] Krogdahl, A., Gajardo, K., Kortner, T.M., Penn, M., Gu, M., Berge, G.M. and Bakke, A.M. (2015) Soya Saponins Induce Enteritis in Atlantic Salmon (*Salmo salar* L.). *Journal of Agricultural and Food Chemistry*, **63**, 3887-3902. https://doi.org/10.1021/jf506242t

[19] Heikkinen, J., Vielma, J., Kemilainen, O., Tiirola, M., Eskelinen, P., Kiuru, T., Na-

via-Paldanius, D. and von Wright, A. (2006) Effects of Soybean Meal Based Diet on Growth Performance, Gut Histopathology and Intestinal Microbiota of Juvenile Rainbow Trout (*Oncorhynchus mykiss*). *Aquaculture*, **261**, 259-268. https://doi.org/10.1016/j.aquaculture.2006.07.012

[20] Bakke, A.M. (2011) Pathophysiological and Immunological Characteristics of Soybean Meal-Induced Enteropathy in Salmon: Contribution of Recent Molecular Investigations. In: Cruz-Suárex, L.E., Ricque-Marie, D., Tapia-Salazar, M., Nieto-López, M.G., Villarreal-Cavazos, D.A., Gamboa-Delgado, J. and Hernández-Hernández, L., Eds., *Proceedings of International Symposium Aquaculture Nutrition XI*, Autonomous University of Nuevo Leon, Monterrey, 345-372.

[21] Salunkhe, D.K., Chavan, J.K., Adsule, R.N. and Kadam, S.S. (1992) World Oil Seeds: Chemistry, Technology, and Utilization. Van Nostrand Reinhold, New York.

[22] Fowler, L.G. (1980) Substitution of Soybean and Cottonseed Products for Fish Meal in Diets Fed to Chinook and Coho Salmon. *The Progressive Fish-Culturist*, **42**, 87-91. https://doi.org/10.1577/1548-8659(1980)42[87:SOSACP]2.0.CO;2

[23] Reinitz, G. (1980) Soybean Meal as a Substitute for Herring Meal in Practical Diets for Rainbow Trout. *The Progressive Fish-Culturist*, **42**, 103-106. https://doi.org/10.1577/1548-8659(1980)42[87:SOSACP]2.0.CO;2

[24] Vielma, J., Makinen, T., Ekholm, P. and Koskela, J. (2000) Influence of Dietary Soy and Phytase Levels on Performance and Body Composition of Large Rainbow Trout (*Oncorhynchus mykiss*) and Algal Availability of Phosphorus Load. *Aquaculture*, **183**, 349-362. https://doi.org/10.1016/S0044-8486(99)00299-9

[25] Francis, G., Makkar, H.P.S. and Becker, K. (2001) Antinutritional Factors Present in Plant-Derived Alternate Fish Feed Ingredients and their Effects in Fish. *Aquaculture*, **199**, 197-227. https://doi.org/10.1016/S0044-8486(01)00526-9

[26] Krogdahl, A., Penn, M., Thorsen, J., Refstie, S. and Bakke, A.M. (2010) Important Antinutrients in Plant Feedstuffs for Aquaculture: An Update on Recent Findings Regarding Responses in Salmonids. *Aquaculture Research*, **41**, 333-344. https://doi.org/10.1111/j.1365-2109.2009.02426.x

[27] Hong, K.-J., Lee, C.-H. and Kim, S.W. (2004) *Aspergillus oryzae* GB-107 Fermentation Improves Nutritional Quality of Food Soybeans and Feed Soybean Meals. *Journal of Medicinal Food*, **7**, 430-435. https://doi.org/10.1089/jmf.2004.7.430

[28] Refstie, S., Sahlstrom, S., Brathen, E., Baeverfjord, G. and Krogedal, P. (2005) Lactic Acid Fermentation Eliminates Indigestible Carbohydrates and Antinutritional Factors in Soybean Meal for Atlantic Salmon (*Salmo salar*). *Aquaculture*, **246**, 331-345. https://doi.org/10.1016/j.aquaculture.2005.01.001

[29] Sotoudeh, E., Moghaddam, J.A., Shahhosseini, G. and Aramli, M.S. (2016) Effect of Dietary Gamma-Irradiated and Fermented Soybean Meal on the Growth Performance, Body Composition, and Digestive Enzymes Activity of Caspian Brown Trout *Salmo trutta caspius*, Juvenile. *Journal of the World Aquaculture Society*, **47**, 830-842. https://doi.org/10.1111/jwas.12297

[30] Parker, T.M. and Barnes, M.E. (2014) Rearing Velocity Impacts on Landlocked Fall Chinook Salmon (*Oncorhynchus tshawytscha*) Growth, Condition, and Survival. *Open Journal of Animal Sciences*, **4**, 244-252. https://doi.org/10.4236/ojas.2014.45031

[31] Parker, T.M. and Barnes, M.E. (2015) Effects of Different Water Velocities on Hatchery Rearing Performance and Recovery From Transportation of Rainbow Trout Fed Two Different Rations. *Transactions of the American Fisheries Society*, **144**, 882-890. https://doi.org/10.1080/00028487.2015.1047533

[32] Good, C., May, T., Crouse, C., Summerfelt, S. and Welch, T.J. (2016) Assessing the Impacts of Swimming Exercise and the Relative Susceptibility of Rainbow Trout *Oncorhynchus mykiss* (Walbaum) and Atlantic Salmon *Salmo salar* L. Following Injection Challenge with *Weissella ceti*. *Journal of Fish Diseases*, **39**, 1387-1391. https://doi.org/10.1111/jfd.12468

[33] Liu, G., Wu, Y., Qin, X., Shi, X. and Wang, X. (2018) The Effect of Aerobic Exercise Training on Growth Performance, Innate Immune Response, and Disease Resistance in Juvenile *Schizothorax prenanti*. *Aquaculture*, **486**, 18-25. https://doi.org/10.1016/j.aquaculture.2017.12.006

[34] Waldrop, T., Summerfelt, S., Mazik, P. and Good, C. (2018) The Effects of Swimming Exercise and Dissolved Oxygen on Growth Performance, Fin Condition and Precocious Maturation of Early-Rearing Atlantic Salmon *Salmo salar*. *Aquaculture Research*, **49**, 801-808. https://doi.org/10.1111/are.13511

[35] Davison, W. and Goldspink, G. (1977) The Effect of Prolonged Exercise on the Lateral Musculature of the Brown Trout (*Salmo trutta*). *Journal of Experimental Biology*, **70**, 1-12.

[36] Association of Official Analytical Chemists (AOAC) (2017) Official Methods of Analysis. http://www.eoma.aoac.org/

[37] American Association of Cereal Chemists (AACC) (2000) Approved Methods of the American Association of Cereal Chemists. 10th Edition, American Association of Cereal Chemists, Saint Paul.

[38] Buterbaugh, G.L. and Willoughby, H. (1967) A Feeding Guide for Brook, Brown and Rainbow Trout. *The Progressive Fish-Culturist*, **29**, 210-215. https://doi.org/10.1577/1548-8640(1967)29[210:AFGFBB]2.0.CO;2

[39] Barnes, M.E., Wintersteen, K., Krebs, E., Nero, P., Tycz, J., Reichert, S. and Zimmerman, S. (2011) 2010 McNenny State Fish Hatchery Annual Production Report. South Dakota Game, Fish and Parks Annual Report 11-03, Pierre.

[40] American Veterinary Medical Association (AVMA) (2013) AVMA Guidelines for the Euthanasia of Animals: 2013 Edition. American Veterinary Medical Association, Schaumburg.

[41] Strange, R.J. (1996) Field Examination of Fishes. In: Murphy, B.R. and Willis, D.W., Eds., *Fisheries Techniques*, 2nd Edition, American Fisheries Society, Bethesda, 433-466.

[42] Goede, R.W. and Barton, B.A. (1990) Organismic Indices and an Autopsy-Based Assessment as Indicators of Health and Condition in Fish. In: Adam, S.M., Ed., *Biological Indicators of Stress in Fish*, American Fisheries Society, Symposium 8, Bethesda, 93-108.

[43] Gu, M., Bai, N., Xu, B., Jia, Q. and Zhang, Z. (2017) Protective Effect of Glutamine and Arginine against Soybean Meal-Induced Enteritis in Juvenile Turbot (*Scophthalmus maximusi*). *Fish & Shellfish Immunology*, **70**, 95-105. https://doi.org/10.1016/j.fsi.2017.08.048

[44] Wang, Y., Wang, L., Zhang, C. and Song, K. (2017) Effects of Substituting Fishmeal with Soybean Meal on Growth Performance and Intestinal Morphology in Orange-Spotted Grouper (*Epinephelus coioides*). *Aquaculture Reports*, **5**, 52-57. https://doi.org/10.1016/j.aqrep.2016.12.005

[45] Booman, M., Forster, I., Vederas, I., Groman, D.B. and Jones, S.R.M. (2018) Soybean Meal-Induced Enteritis in Atlantic Salmon (*Salmo salar*) and Chinook Salmon (*Oncorhynchus tshawytscha*) but Not in Pink Salmon (*O. gorbuscha*). *Aquaculture*, **483**, 238-243. https://doi.org/10.1016/j.aquaculture.2017.10.025

[46] Novriadi, R., Rhodes, M., Powell, M., Hanson, T. and Davis, D.A. (2018) Effects of Soybean Meal Replacement with Fermented Soybean Meal on Growth, Serum Biochemistry, and Morphological Condition of Liver and Distal Intestine of Florida Pompano *Trachinotus carolinus*. *Aquaculture Nutrition*, **24**, 1066-1075. https://doi.org/10.1111/anu.12645

[47] Bureau, D.P., Harris, A.M. and Cho, C.Y. (1998) The Effects of Purified Alcohol Extracts from Soy Products on Feed Intake and Growth of Chinook Salmon (*Oncorhynchus tshawytscha*) and Rainbow Trout (*Oncorhynchus mykiss*). *Aquaculture*, **161**, 27-43. https://doi.org/10.1016/S0044-8486(97)00254-8

[48] Burrells, C., Williams, P.D., Southgate, P.J. and Crampton, V.O. (1999) Immunological, Physiological and Pathological Responses of Rainbow Trout (*Oncorhynchus mykiss*) to Increasing Dietary Concentrations of Soybean Proteins. *Veterinary Immunology and Immunopathology*, **72**, 277-288. https://doi.org/10.1016/S0165-2427(99)00143-9

[49] Knudsen, D., Uran, P., Arnous, A., Koppe, W. and Frokiaer, H. (2007) Saponin-Containing Subfractions of Soybean Molasses Induce Enteritis in the Distal Intestine of Atlantic Salmon. *Journal of Agriculture and Food Chemistry*, **55**, 2261-2267. https://doi.org/10.1021/jf0626967

[50] Colburn, H.R., Walker, A.B., Breton, T.S., Stilwell, J.M., Sidor, I.F., Gannam, A.L. and Berlinsky, D.L. (2012) Partial Replacement of Fishmeal with Soybean Meal and Soy Protein Concentrate in Diets of Atlantic Cod. *North American Journal of Aquaculture*, **74**, 330-337. https://doi.org/10.1080/15222055.2012.676008

[51] Barnes, M.E., Brown, M.L., Bruce, T., Sindelar, S. and Neiger, R. (2014) Rainbow Trout Rearing Performance, Intestinal Morphology, and Immune Response after Long-Term Feeding of High Levels of Fermented Soybean Meal. *North American Journal of Aquaculture*, **76**, 333-345. https://doi.org/10.1080/15222055.2014.920748

[52] Bruce, T.J., Sindelar, S.C., Voorhees, J.M., Brown, M.L. and Barnes, M.E. (2017) Performance and Immunological Responses of Rainbow Trout (*Oncorhynchus mykiss*) Fed Bioprocessed Plant-Based Proteins. *Aquaculture Nutrition*, **23**, 1160-1168. https://doi.org/10.1111/anu.12485

[53] Bruce, T.J., Neiger, R.D. and Brown, M.L. (2018) Gut Histology, Immunology and the Intestinal Microbiota of Rainbow Trout, *Oncorhynchus mykiss* (Walbaum), Fed Process Variants of Soybean Meal. *Aquaculture Research*, **49**, 492-504. https://doi.org/10.1111/are.13480

[54] Barnes, M.E., Brown, M.L., Rosentrater, K.A. and Sewell, J.R. (2012) An Initial Investigation Replacing Fish Meal with a Commercial Fermented Soybean Meal Product in the Diets of Juvenile Rainbow Trout. *Open Journal of Animal Sciences*, **2**, 234-243. https://doi.org/10.4236/ojas.2012.24033

[55] Barnes, M.E., Brown, M.L., Bruce, T.J., Neiger, R. and Sindelar, S. (2015) Effects of Fermented Soybean Meal Diet on Rainbow Trout Mortality and Immune Function during a Disease Outbreak. *Journal of Aquaculture Feed Science and Nutrition*, **7**, 6-15. http://medwelljournals.com/abstract/?doi=joafsnu.2015.6.15

[56] Yamamoto, T., Iwashita, Y., Matsunari, H., Sugita, T., Furuita, H., Akimoto, A., Okamatsu, K. and Suzuki, N. (2010) Influence of Fermentation Conditions for Soybean Meal in a Non-Fish Meal Diet on Growth Performance and Physiological Condition of Rainbow Trout *Oncorhynchus mykiss*. *Aquaculture*, **309**, 173-180. https://doi.org/10.1016/j.aquaculture.2010.09.021

[57] Yamamoto, T., Matsunari, H., Sugita, T., Furuita, H., Masumoto, T., Iwashita, Y., Amano, S. and Suzuki, N. (2012) Optimization of the Supplemental Essential Ami-

no Acids to a Fish Meal-Free Diet Based on Fermented Soybean Meal for Rainbow Trout *Oncorhynchus mykiss*. *Fish Science*, **78**, 359-366. https://doi.org/10.1007/s12562-011-0456-2

[58] Refstie, S., Landsverk, T., Bakke-McKellep, A.M., Ringø, E., Sundby, A., Shearer, K.D. and Krogdahl, A. (2006) Digestive Capacity, Intestinal Morphology, and Microflora of 1-Year and 2-Year Old Atlantic Cod (*Gadus morhua*) Fed Standard or Bioprocessed Soybean Meal. *Aquaculture*, **261**, 269-284. https://doi.org/10.1016/j.aquaculture.2006.07.011

[59] Ringø, E., Sperstad, S., Myklebust, R., Refstie, S. and Krogdahl, A. (2006) Characterisation of the Microbiota Associated with Intestine of Atlantic Cod (*Gadus morhus* L.) the Effect of Fish Meal, Standard Soybean Meal and a Bioprocessed Soybean Meal. *Aquaculture*, **261**, 829-841. https://doi.org/10.1016/j.aquaculture.2006.06.030

[60] Zhou, F., Song, W., Shao, Q., Peng, X., Xiao, J., Hua, Y. and Owari, B.N. (2011) Partial Replacement of Fish Meal by Fermented Soybean Meal in Diets for Black Sea Bream, *Acanthopagrus schlegelii*, Juveniles. *Journal of the World Aquaculture Society*, **42**, 184-197. https://doi.org/10.1111/j.1749-7345.2011.00455.x

[61] Azarm, H.M. and Lee, S.-M. (2014) Effects of Partial Substitution of Dietary Fish Meal by Fermented Soybean Meal on Growth Performance, Amino Acid and Biochemical Parameters of Juvenile Black Sea Bream *Acanthopagrus schlegeli*. *Aquaculture Research*, **45**, 994-1003. https://doi.org/10.1111/are.12040

[62] Yuan, Y.C., Lin, Y.C., Yang, H.J., Gong, Y., Gong, S.Y. and Yu, D.H. (2012) Evaluation of Fermented Soybean Meal in Practical Diets for Juvenile Chinese Sucker, *Myxocyprinus asiaticus*. *Aquaculture Nutrition*, **19**, 74-83. https://doi.org/10.1111/j.1365-2095.2012.00939.x

[63] Kokou, F., Rigos, G., Henry, M., Kentouri, M. and Alexis, M. (2012) Growth Performance, Feed Utilization and Non-Specific Immune Response of Gilthead Sea Bream (*Sparus aurata* L.) Fed Graded Levels of Bioprocessed Soybean Meal. *Aquaculture*, **364-365**, 74-81.

[64] Kader, M.A., Koshio, S., Ishikawa, M., Yokoyama, S., Bulbul, M., Nguyen, B.T., Gao, J. and Laining, A. (2012) Can Fermented Soybean Meal and Squid By-Product Blend Be Used as Fishmeal Replacements for Japanese Flounder (*Paralichthys olivaceus*)? *Aquaculture Research*, **43**, 1427-1438.

[65] Jiang, Y., Zhao, P.-F., Lin, S.-M., Tang, R.-J., Chen, Y.-J. and Luo, L. (2018) Partial Substitution of Soybean Meal with Fermented Soybean Residue in Diets for Juvenile Largemouth Bass, *Micropterus salmoides*. *Aquaculture Nutrition*, **24**, 1213-1222.

[66] Shiu, Y.-L., Hsieh, S.-L., Guei, W.-C., Tsai, Y.-T., Chiu, C.-H. and Liu, C.-H. (2015) Using *Bacillus subtilis* E20-Fermented Soybean Meal as Replacement for Fish Meal in the Diet of Orange-Spotted Grouper (*Epinephelus coioides*, Hamilton). *Aquaculture Research*, **46**, 1403-1416. https://doi.org/10.1111/are.12294

[67] Chiu, S.-T., Wong, S.-L., Shiu, Y.-L., Chiu, C.-H., Guei, W.-C. and Liu, C.-H. (2016) Using a Fermented Mixture of Soybean Meal and Earthworm Meal to Replace Fish Meal in the Diet of White Shrimp, *Penaeu vannamei* (Boone). *Aquaculture Research*, **47**, 3489-3500. https://doi.org/10.1111/are.12799

[68] Van Nguyen, N., Hoang, L., Van Khanh, T., Duy Hai, P. and Hung, L.T. (2018) Utilization of Fermented Soybean Meal for Fishmeal Substitution in Diets of Pacific White Shrimp (*Litopenaeus vannamei*). *Aquaculture Nutrition*, **24**, 1092-1100. https://doi.org/10.1111/anu.12648

[69] Lee, S.-M., Azarm, H.M. and Chang, K.H. (2016) Effects of Dietary Inclusion of Fermented Soybean Meal on Growth, Body Composition, Antioxidant Enzyme Ac-

tivity and Disease Resistance of Rockfish (*Sebastes schlegeli*). *Aquaculture*, **459**, 110-116. https://doi.org/10.1016/j.aquaculture.2016.03.036

[70] Trushenski, J.T., Rombenso, A.N., Page, M., Jirsa, M. and Drawbridge, M. (2014) Traditional and Fermented Soybean Meal as Ingredients in Feed for White Seabass and Yellowtail Jack. *North American Journal of Aquaculture*, **76**, 312-322. https://doi.org/10.1080/15222055.2014.911227

[71] Barrows, F.T., Gaylord, T.G., Sealey, W.M., Porter, L. and Smith, C.E. (2008) The Effect of Vitamin Premix in Extruded Plant-Based and Fish Meal Based Diets on Growth Efficiency and Health of Rainbow Trout. *Aquaculture*, **283**, 148-155. https://doi.org/10.1016/j.aquaculture.2008.07.014

[72] Merrifield, D.L., Dimitroglou, A., Bradley, G., Baker, R.T.M. and Davies, S.J. (2009) Soybean Meal Alters Autochthonous Microbial Populations, Microvilli Morphology and Compromises Intestinal Enterocyte Integrity of Rainbow Trout (*Oncorhynchus mykiss*). *Journal of Fish Diseases*, **32**, 755-766. https://doi.org/10.1111/j.1365-2761.2009.01052.x

[73] Johnsen, C.A., Hagen, Ø. and Bendiksen, E.A. (2011) Long-Term Effects of High-Energy, Low-Fishmeal Feed on Growth and Characteristics of Atlantic Salmon (*Salmo salar* L.). *Aquaculture*, **312**, 109-116. https://doi.org/10.1016/j.aquaculture.2010.12.012

[74] Weathercup, R.N. and McCraken, K.J. (1999) Changes in Rainbow Trout (*Oncorhynchus mykiss* Walbaum), Body Composition with Weight. *Aquaculture Research*, **30**, 305-307. https://doi.org/10.1046/j.1365-2109.1999.00320.x

[75] de Francesco, M., Parisi, G., Médale, F., Lupi, P., Kaushik, S.J. and Poli, B.M. (2004) Effect of Long-Term Feeding with a Plant Protein Mixture Based Diet on Growth and Body Fillet Quality Traits of Large Rainbow Trout (*Oncorhynchus mykiss*). *Aquaculture*, **236**, 413-429. https://doi.org/10.1016/j.aquaculture.2004.01.006

[76] Kissil, G.W., Lupatsch, I., Higgs, D.A. and Hardy, R.W. (2000) Dietary Substitution of Soy and Rapeseed Protein Concentrations for Fish Meal, and Their Effects on Growth and Nutrient Utilization in Gilthead Seabream *Sparus aurata* L. *Aquaculture Research*, **31**, 595-601. https://doi.org/10.1046/j.1365-2109.2000.00477.x

[77] Regost, C., Arzel, J., Cardinal, M., Laroche, M. and Kaushik, S.J. (2001) Fat Depositin and Flesh Quality in Seawater Reared, Triploid Brown Trout (*Salmo trutta*) as Affected by Dietary Fat Levels and Starvation. *Aquaculture*, **193**, 325-345. https://doi.org/10.1016/S0044-8486(00)00498-1

[78] Kizak, V., Güner, Y., Türel, M. and Kayim, M. (2013) Comparison of Growth Performance, Gonadal Structure, and Erythrocyte Size in Triploid and Diploid Brown Trout (*Salmo trutta fario* L., 1758). *Turkish Journal of Fisheries and Aquatic Sciences*, **13**, 571-580.

[79] De Silva, S.S. and Anderson, T.A. (1995) Fish Nutrition in Aquaculture. Chapman and Hall, London.

[80] Stickney, R.R. (1994) Principles of Aquaculture. Wiley & Sons, New York.

[81] Pirhonen, J., Schreck, C.B. and Gannam, A. (2000) Appetite of Chinook Salmon (*Oncorhynchus tshawytscha*) Naturally Infected with Bacterial Kidney Disease. *Aquaculture*, **189**, 1-10. https://doi.org/10.1016/S0044-8486(00)00368-9

[82] Romarheim, O.H., Skrede, A., Gao, Y., Krogdahl, Å., Denstadli, V., Lilleeng, E. and Storebakken, T. (2008) Comparison of White Flakes and Toasted Soybean Meal Partly Replacing Fish Meal as Protein Source in Extruded Feed for Rainbow Trout (*Oncorhynchus mykiss*). *Aquaculture*, **256**, 354-364. https://doi.org/10.1016/j.aquaculture.2006.02.006

[83] Sealey, W.M., Barrows, F.T., Smith, C.E., Overturf, K. and LaPatra, S.E. (2009) Soybean Meal Level and Probiotics in First Feeding Fry Diets Alter the Ability of Rainbow Trout *Oncorhynchus mykiss* to Utilize High Levels of Soybean Meal during Grow-Out. *Aquaculture*, **293**, 195-203. https://doi.org/10.1016/j.aquaculture.2009.04.013

[84] Barrows, F.T., Gaylord, T.G., Sealey, W.M., Haas, M.J. and Stroup, R.L. (2008) Processing Soybean Meal for Biodiesel Production: Effect of a New Processing Method on Growth Performance of Rainbow Trout (*Oncorhynchus mykiss*). *Aquaculture*, **283**, 141-147. https://doi.org/10.1016/j.aquaculture.2008.06.041

[85] van den Ingh, T.S.G.A.M., Krogdahl, Å., Olli, J.J., Hendricks, H.G.C.J.M. and Koninkx, J.G.J.F. (1991) Effects of Soybean-Containing Diets on the Proximal and Distal Intestine in Atlantic Salmon (*Salmo salar*): A Morphological Study. *Aquaculture*, **94**, 297-305. https://doi.org/10.1016/0044-8486(91)90174-6

[86] Baeverfjord, G. and Krogdahl, Å. (1996) Development and Regression of Soybean Meal Induced Enteritis in Atlantic Salmon, *Salmo salar* L., Distal Intestine: A Comparison with the Intestines of Fasted Fish. *Journal of Fish Diseases*, **19**, 375-387.

[87] Bakke-McKellep, A.M., Press, C.M., Baeverfjord, G., Krogdahl, Å. and Landsverk, T. (2000) Changes in Immune and Enzyme Histochemical Phenotypes of Cells in the Intestinal Mucosa of Atlantic Salmon, *Salmo salar* L., with Soybean Meal-Induced Enteritis. *Journal of Fish Diseases*, **23**, 115-127. https://doi.org/10.1046/j.1365-2761.2000.00218.x

[88] Bakke-McKellep, A.M., Penn, M.H., Salas, P.M., Refstie, S., Sperstad, S., Landsverk, T., Ringo, E. and Krogdahl, Å. (2007) Effects of Dietary Soyabean Meal, Insulin and Oxytetracycline on Intestinal Microbiota and Epithelial Stress, Apoptosis and Proliferation in the Teleost Atlantic Salmon (*Salmo salar* L.). *British Journal of Nutrition*, **97**, 699-713. https://doi.org/10.1017/S0007114507381397

[89] Barnes, M.E., Brown, M.L., Rosentrater, K.A. and Sewell, J.R. (2013) Preliminary Evaluation of Rainbow Trout Diets Containing PepSoyGen, a Fermented Soybean Meal Product, and Additional Amino Acids. *The Open Fish Science Journal*, **6**, 19-27. https://doi.org/10.2174/1874401X01306010019

[90] Barnes, M.E., Brown, M.L. and Neiger, R. (2015) Comparative Performance of Two Rainbow Trout Strains Fed Fermented Soybean Meal. *Aquaculture International*, **23**, 1227-1238. https://doi.org/10.1007/s10499-015-9879-6

[91] Daniels, W.H. and Robinson, E.H. (1986) Protein and Energy Requirements of Juvenile Red Drum (*Sciaenops ocellatus*). *Aquaculture*, **53**, 243-252. https://doi.org/10.1016/0044-8486(86)90354-6

[92] Kim, J.D. and Kaushik, S.J. (1992) Contributions of Digestible Energy from Carbohydrates and Estimation of Protein/Energy Requirements for Growth of Rainbow Trout (*Oncorhynchus mykiss*). *Aquaculture*, **106**, 161-169. https://doi.org/10.1016/0044-8486(92)90200-5

[93] Barton, B.A., Morgan, J.D. and Vijayan, M.M. (2002) Physiological and Condition-Related Indicators of Environmental Stress in Fish. In: Adams, S.M., Ed., *Biological Indicators of Aquatic Ecosystem Stress*, American Fisheries Society, Bethesda, 111-148.

[94] Sotoudeh, E., Kenari, A.A. and Rezaei, M.H. (2011) Growth Response, Body Composition and Fatty Acid Profile of Caspian Brown Trout (*Salmo trutta Caspius*) Juvenile Fed Diets Containing Different Levels of Soybean Phosphatidylcholine. *Aquaculture International*, **19**, 611-623. https://doi.org/10.1007/s10499-010-9376-x

[95] Mambrini, M., Labbé, L., Randriamanantsoa, F. and Boujard, T. (2006) Response of

Growth-Selected Brown Trout (*Salmo trutta*) Challenging Feeding Conditions. *Aquaculture*, **252**, 429-440. https://doi.org/10.1016/j.aquaculture.2005.07.001

[96] Jobling, M., Koskela, J. and Savolainen, R. (1998) Influence of Dietary Fat Level and Increased Adiposity on Growth and Fat Deposition in Rainbow Trout (*Oncorhynchus mykiss* Walbaum). *Aquaculture Research*, **29**, 601-607.

[97] Company, R., Calduch-Giner, J.A., Kaushik, S. and Perez-Sanchez, J. (1999) Growth Performance and Adiposity in Gilthead Sea Bream (*Sparus aurata*): Risks and Benefits of High Energy Diets. *Aquaculture*, **171**, 279-292. https://doi.org/10.1016/S0044-8486(98)00495-5

[98] Yildiz, M., Sener, E. and Timur, M. (2006) Effect of Seasonal Change and Different Commercial Feeds on Proximate Composition of Sea Bream (*Sparus aurata*). *Turkish Journal of Fisheries and Aquatic Sciences*, **6**, 99-104.

[99] Smith, L.S. (1991) Introduction to Fish Physiology. Argent Laboratories Press, Redmond.

[100] Kientz, J.L. and Barnes, M.E. (2016) Structural Complexity Improves the Rearing Performance of Rainbow Trout in Circular Tanks. *North American Journal of Aquaculture*, **78**, 203-207. https://doi.org/10.1080/15222055.2016.1159629

[101] Leon, K.A. (1986) Effect of Exercise on Feed Consumption, Growth, Food Conversion, and Stamina of Brook Trout. *The Progressive Fish-Culturist*, **48**, 43-46. https://doi.org/10.1577/1548-8640(1986)48<43:EOEOFC>2.0.CO;2

[102] Houlihan, D.F. and Laurent, P. (1987) Effects of Exercise Training on Performance, Growth, and Protein Turnover or Rainbow Trout (*Salmo gairdneri*). *Canadian Journal of Fisheries and Aquatic Sciences*, **44**, 1614-1621. https://doi.org/10.1139/f87-195

[103] Christiansen, J.S. and Jobling, M. (1990) The Behavior and the Relationship between Food Intake and Growth of Juvenile Artic Charr, *Salvelinus alpinus* L., Subjected to Sustained Exercise. *Canadian Journal of Zoology*, **68**, 2185-2191. https://doi.org/10.1139/z90-303

[104] Young, P.S. and Cech Jr., J.J. (1993) Improved Growth, Swimming Performance, and Muscular Development in Exercise-Conditioned Young-of-the-Year Striped Bass (*Morone saxatilis*). *Canadian Journal of Fisheries and Aquatic Science*, **50**, 703-707. https://doi.org/10.1139/f93-080

[105] Castro, V., Grisdale-Helland, B., Helland, S.J., Kristensen, T., Jørgensen, S.M., Helgerud, J., Claireaux, G., Farrell, A.P., Krasnov, A. and Takle, H. (2011) Aerobic Training Stimulates Growth and Promotes Disease Resistance in Atlantic Salmon (*Salmo salar*). *Comparative Biochemistry and Physiology Part A*: *Molecular & Integrative Physiology*, **160**, 278-290. https://doi.org/10.1016/j.cbpa.2011.06.013

[106] Gallaugher, P.E., Thorarensen, H., Kiessling, A. and Farrell, A.P. (2001) Effects of High Intensity Exercise Training on Cardiovascular Function, Oxygen Uptake, Internal Oxygen Transport and Osmotic Balance in Chinook Salmon (*Oncorhynchus tshawytscha*) during Critical Speed Swimming. *The Journal of Experimental Biology*, **204**, 2861-2872.

[107] Noakes, T.D. (2000) Physiological Models to Understand Exercise Fatigue and the Adaptations that Predict or Enhance Athletic Performance. *Scandinavian Journal of Medicine and Science in Sports*, **10**, 123-145. https://doi.org/10.1034/j.1600-0838.2000.010003123.x

[108] Noakes, T.D., St Clair Gibson, A. and Lambert, E.V. (2005) From the Catastrophe to Complexity: A Novel Model of Integrative Central Neural Regulation of Effort and Fatigue during Exercise in Humans: Summary and Conclusions. *British Journal of*

Sports Medicine, **39**, 120-124. https://doi.org/10.1136/bjsm.2003.010330

[109] Crewe, H., Tucker, R. and Noakes, T.D. (2008) The Rate of Increase in Rating of Perceived Exertion Predicts the Duration of Exercise to Fatigue at a Fixed Power Output in Different Environmental Conditions. *European Journal of Applied Physiology*, **103**, 569-577. https://doi.org/10.1007/s00421-008-0741-7

[110] Joyner, M.J. and Coyle, E.F. (2008) Endurance Exercise Performance: The Physiology of Champions. *The Journal of Physiology*, **586**, 35-44. https://doi.org/10.1113/jphysiol.2007.143834

[111] Kiessling, A., Higgs, D., Dosanjh, B. and Eales, J. (1994) Influence of Sustained Exercise at Two Ration Levels on Growth and Thyroid Function of All-Female Chinook Salmon (*Oncorhynchus tshawytscha*) in Seawater. *Canadian Journal of Fisheries and Aquatic Sciences*, **51**, 1975-1984. https://doi.org/10.1139/f94-200

[112] Azevedo, P.A., Cho, C.Y., Leeson, S. and Bureau, D.P. (1998) Effects of Feeding Level and Water Temperature on Growth, Nutrient and Energy Utilization and Waste Outputs of Rainbow Trout (*Oncorhynchus mykiss*). *Aquatic Living Resources*, **11**, 227-238. https://doi.org/10.1016/S0990-7440(98)89005-0

[113] Rasmussen, R.S. and Ostenfeld, T.H. (2000) Effect of Growth Rate on Quality Traits and Feed Utilisation of Rainbow Trout (*Oncorhynchus mykiss*) and Brook Trout (*Salvelinus fontinalis*). *Aquaculture*, **184**, 327-337. https://doi.org/10.1016/S0044-8486(99)00324-5

[114] Latremouille, D.N. (2003) Fin Erosion in Aquaculture and Natural Environments. *Reviews in Fisheries Science*, **11**, 315-335. https://doi.org/10.1080/10641260390255745

[115] Wagner, E.J., Intelmann, S.S. and Routledge, D. (1996) The Effect of Fry Rearing Density on Hatchery Performance, Fin Condition, and Agonistic Behavior or Rainbow Trout *Oncorhynchus mykiss* Fry. *Journal of the World Aquaculture Society*, **27**, 264-274. https://doi.org/10.1111/j.1749-7345.1996.tb00608.x

[116] Lemm, C.A., Rottiers, D.V. Dropkin, D.S. and Dennison, B.A. (1988) Growth, Composition, and Fin Quality of Atlantic Salmon Fed Different Diets at Seasonal Temperatures in a Laboratory and Hatchery. U.S. Fish and Wildlife Service Biological Report 88, 1-12.

[117] Kindschi, G.A., Shaw, H.T. and Bruhn, D.S. (1991) Effect of Diet on Performance, Fin Quality, and Dorsal Skin Lesions in Steelhead. *Journal of Applied Aquaculture*, **1**, 113-120. https://doi.org/10.1300/J028v01n01_10

[118] Devesa, S., Barja, J.L. and Toranzo, A.E. (1989) Ulcerative Skin and Fin Lesions in Reared Turbot, *Scopthalmus maximus* (L.). *Journal of Fish Diseases*, **12**, 323-333. https://doi.org/10.1111/j.1365-2761.1989.tb00321.x

[119] Bosakowski, T. and Wagner, E.J. (1995) Experimental Use of Cobble Substrates in Concrete Raceways for Improving Fin Condition of Cutthroat (*Oncorhynchus clarki*) and Rainbow Trout (*O. mykiss*). *Aquaculture*, **130**, 159-165. https://doi.org/10.1016/0044-8486(94)00223-B

[120] Bosakowski, T. and Wagner, E.J. (1994) Assessment of Fish Erosion by Comparison of Relative Fin Length in Hatchery and Wild Trout in Utah. *Canadian Journal of Fisheries and Aquatic Sciences*, **51**, 636-641. https://doi.org/10.1139/f94-064

[121] Miller, S.A., Wagner, E.J. and Bosakowski, T. (1995) Performance and Oxygen Consumption of Rainbow Trout Reared at Two Densities in Raceways with Oxygen Supplementation. *The Progressive Fish-Culturist*, **57**, 206-212. https://doi.org/10.1577/1548-8640(1995)057<0206:PAOCOR>2.3.CO;2

[122] Wagner, E.J., Jeppsen, T., Arndt, R., Routledge, M.D. and Bradwisch, Q. (1997) Effects of Rearing Density upon Cutthroat Trout Hematology, Hatchery Performance, Fin Erosion, and General Health Condition. *The Progressive Fish-Culturist*, **59**, 173-187. https://doi.org/10.1577/1548-8640(1997)059<0173:EORDUC>2.3.CO;2

[123] North, B.P., Turnbull, J.F., Ellis, T., Porter, M.J., Migaud, H., Bron, J. and Bromage, N.R. (2006) The Impact of Stocking Density on the Welfare of Rainbow Trout (*Oncorhynchus mykiss*). *Aquaculture*, **255**, 466-479. https://doi.org/10.1016/j.aquaculture.2006.01.004