



Received: 11 July 2018
Accepted: 01 February 2019
First Published: 07 February 2019

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Reviewing editor:
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ANIMAL HUSBANDRY & VETERINARY SCIENCE | RESEARCH ARTICLE

Bioprocessed soybean meal replacement of fish meal in rainbow trout (*Oncorhynchus mykiss*) diets

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Abstract: This 125-day experiment evaluated the growth of adult rainbow trout (*Oncorhynchus mykiss*) fed one of three isonitrogenous and isocaloric diets (46% protein, 16% lipid). Fish meal was the primary protein source for the reference diet, which was compared to two other diets where bioprocessed soybean meal replaced 60% or 80% of the dietary fish meal. At the end of the experiment, there were no significant differences in gain, percent gain, feed conversion ratio, or specific growth rate among the dietary treatments. There were also no significant differences in intestinal morphology, splenosomatic index, hepatosomatic index, and viscerosomatic index among the diets. Based on these results, bioprocessed soybean meal can replace at least 80% of the fish meal in adult rainbow trout diets.

Subjects: Environment & Agriculture; Bioscience; Food Science & Technology

Keywords: bioprocessed soybean meal; rainbow trout; *Oncorhynchus mykiss*; diet; fish meal

1. Introduction

Plant-based proteins, such as soybeans (*Glycine max*), have been extensively researched as alternatives to dietary fish meal (Gatlin III et al., 2007; Li & Robinson, 2015; Nordrum, Bakke-McKellep, Krogdahl, & Buddington, 2000). Alternative protein sources are needed due to the exponential growth of aquaculture without a corresponding increase in sources of fish meal, which is primarily made from small

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PUBLIC INTEREST STATEMENT

Aquaculture is rapidly growing to feed the increasing number of people in the world. Many farmed fish diets have contained large amounts of fish meal, which is primarily made from small ocean fish like anchovies or menhaden. Because fish meal supplies are limited, feed for some farmed fish can become expensive and limiting. Soybean meal is much more abundant and sustainable than fish meal, but soybean meal cannot be digested by carnivorous fish like trout and salmon. By-processing, such as fermentation, can make soybeans a better food source for fish. This study showed that bioprocessed soybean meal can replace almost all of the fish meal in the diet of rainbow trout.

pelagic fish (Food and Agriculture Organization of the United Nations (FAO), 2016). Thus, there needs to be other suitable and cost-effective protein sources to replace dietary fish meal.

Soybean products are one of the leading alternatives to fish meal in aquaculture diets (Li & Robinson, 2015; Nordrum et al., 2000). Soybeans are highly palatable (Refstie et al., 2000; Sugiura, Dong, Rathbone, & Hardy, 1998; Watanabe, 2002), high in protein, and have a balanced amino acid profile (Gatlin III et al., 2007; National Research Council (NRC), 2011). However, soybeans also have antinutritional factors that hinder fish digestion (Iwashita, Yamamoto, & Furuita et al., 2008; NRC, 2011; Teng et al., 2012), and can also cause gastrointestinal issues, such as enteritis (Heikkinen et al., 2006; Krogdahl, Bakke-McKellep, & Roed et al., 2000; Krogdahl et al., 2015; Refstie et al., 2000). Soybeans also have high levels of carbohydrates (Gatlin III et al., 2007; Salunkhe, Adsule, Chavan, & Kadam, 1992), which can be deleterious to many carnivorous fish species (NRC, 2011). These antinutritional factors and carbohydrates limit the dietary inclusion levels of soybean products for many carnivorous species (Fowler, 1980; NRC, 2011; Vielma, Makinen, Ekholm, & Koskela, 2000).

Nevertheless, there are ways to decrease or eliminate the antinutritional factors in soybeans. Heat occurring during the feed-extrusion process decreases lectins and proteinase inhibitors (Bakke et al., 2011; Barrows, Stone, & Hardy, 2007; Gatlin III et al., 2007; Krogdahl, Penn, Thorsen, Refstie, & Bakke, 2010). Saponins, sterols, and oligosaccharides can be decreased by alcohol extraction (Krogdahl et al., 2010). Bioprocessing, or fermentation, has also been shown to eliminate or reduce many antinutritional factors (Hong, Lee, & Kim, 2004; Refstie, Sahlstrom, Brathen, Baeverfjord, & Krogedal, 2005; Yamamoto et al., 2010, 2012).

Only a limited number of studies have examined soybean meal bioprocessed by fermentation (Barnes, Brown, Bruce, Neiger, & Sindelar, 2015b; Barnes, Brown, Bruce, Sindelar, & Neiger, 2014; Barnes, Brown, & Neiger, 2015a; Barnes, Brown, & Rosentrater et al., 2012; Barnes, Brown, Rosentrater, & Sewell, 2013; Moniruzzaman et al., 2018; Yamamoto et al., 2010, 2012) or other methods (Bruce, Neiger, & Brown, 2017a; Bruce, Sindelar, Voorhees, Brown, & Barnes, 2017b) in rainbow trout (*Oncorhynchus mykiss*) diets. The objective of this study was to examine the effects of a novel bioprocessed soybean meal (BSM) on the rearing performance of rainbow trout.

2. Methods

This feed trial was conducted indoors at McNenny State Fish Hatchery, Spearfish, South Dakota, using degassed and aerated well water at a constant temperature of 11° C (total hardness as CaCO₃, 360 mg/L; alkalinity as CaCO₃, 210 mg/L; pH, 7.6; total dissolved solids, 390 mg/L) in a single-pass, flow-through system.

Seventy-two Erwin x Arlee strain rainbow trout (initial weight 130.7 ± 4.2 g, length 213.2 ± 2.0 mm, mean ± SE) were randomly selected and stocked into one of 12 semi-circular fiberglass tanks (190-L) on 15 June 2016, at six fish per tank (n = 4). Flow rates were kept constant throughout the 125-day study.

Three different diets were used (Table 1), with a modified soybean meal replacing 0%, 60%, or 80% of the fish meal as the primary protein source. The modified soybean meal was produced using a proprietary microbial conversion process (SDSU, Brookings, SD, USA). All of the diets were isocaloric and isonitrogenous, and were all manufactured by cooking extrusion (ExtruTech model 325, Sabetha, KS) at Prairie Aquatech (Brookings, SD). Feed was analyzed according to Association of Official Analytical Chemists (AOAC) (2009) method 2001.11 for protein, 2003.5 (modified by substituting petroleum ether for diethyl ether) for crude lipid, and American Association of Cereal Chemists (AACC) (2000) method 08-03 for ash content.

The individual fish weights were combined to obtain total tank weight. Fish were individually weighed and measured approximately every four weeks. Weight gain, percent gain, feed

Table 1. Diet formulation and composition analyses of the diets used in the 125-day trial. Analysis conducted on post-extrusion feed pellets

Ingredients	Diet (%)		
	1	2	3
Fish meal ^a	35.0	14.0	4.7
Bioprocessed soybean meal ^b	0.0	12.0	30.3
Wheat midds ^c	12.0	10.0	10.0
Whole wheat ^c	17.7	15.2	15.1
Poultry byproduct meal ^d	10.0	15.0	15.0
Blood meal ^e	2.0	2.0	2.0
Feather meal ^d	7.0	2.5	2.5
Vitamin premix ^f	1.3	1.3	1.3
Mineral premix ^f	0.8	2.0	2.0
Micro-mineral premix ^f	0.8	0.8	0.8
Choline chloride ^g	0.6	0.6	0.7
L-Lysine ^h	1.5	2.0	2.0
L-Methionine ⁱ	0.3	0.5	0.5
Stay-C 35 ^j	0.2	0.2	0.2
Fish oil ^k	11.0	13.0	13.0
Total	100	100	100
Chemical analysis (% dry basis)			
Protein	43.18	43.85	43.84
Lipid	15.91	14.28	16.44
Ash	2.42	3.60	3.92
Nitrogen-free extract	20.48	24.33	23.96
Dry matter	93.00	95.20	96.25
Gross Energy (kJ/g)	16.5	16.0	16.8
Protein: Energy (MJ/g)	26.2	27.4	26.0

^aSpecial Select, Omega Protein, Houston, TX.

^bSDSU.

^cConsumer Supply, Sioux City, IA.

^dTyson Foods, Springdale, AR.

^eMason City Byproducts, Mason City, IA.

^fNutraBlend, Neosho, MO.

^gBalchem, New Hampton, NY.

^hCJ Bio America, Fort Dodge, IA.

ⁱAdisseo USA, Alpharreta, GA.

^jDSM Nutritional Products, Ames, IA.

^kVirginia Prime Gold, Omega Protein, Houston, TX.

conversion ratio (FCR), and specific growth rate (SGR) were calculated for each individual tank. Individual fish weights and total lengths were used to calculate Fulton's condition factor (K).

Fish were fed by hand daily, except on the days they were weighed and measured (days 30, 61, 92, and 125). Feeding amounts were initially determined by the hatchery constant method (Butterbaugh & Willoughby, 1967), with planned feed conversion rates of 1.1 and maximum growth rate of 0.08 cm/day, which was based on historical maximum growth rate of Erwin x Arlee strain rainbow trout at McNenny State Fish Hatchery (Barnes et al., 2011), and then adjusted daily to be at or near satiation. Total feed fed and mortalities were recorded daily.

To collect weight and length data on 30-day intervals, the fish were anesthetized using 60 mg/L MS-222 (Tricaine-S, tricaine methanesulfonate, Syndel USA, Ferndale, Washington). On day 125, fish were euthanized using a lethal dose of 250 mg/L MS-222 (American Veterinary Medical Association (AVMA), 2013). In addition to weight and length measurements, fin lengths to the nearest 1.0 mm, and organ (spleen, liver, and visceral) weights to the nearest 1.0 mg, were recorded from three randomly selected trout per tank. Fin indices, hepatosomatic index (HSI) (Strange, 1996), splenosomatic index (SSI) (Goede & Barton, 1990), and viscerosomatic index (VSI) (Goede & Barton, 1990) were calculated for individual fish.

The following equations were used:

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

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

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

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

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

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

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

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

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

A 2-mm wide section of the distal intestine was removed from three randomly selected fish per tank to assess any soy-induced enteritis (Booman, Forster, Vederas, Groman, & Jones, 2018; Gu et al., 2017; Novriadi, Rhodes, Powell, Hanson, & Davis, 2017; Wang, Wang, Zhang, & Song, 2017). After dissection, the intestinal tissue was immediately placed in 10% buffered formalin, and stained with hematoxylin and eosin using standard histological techniques (Bureau, Harris, & Cho, 1998; Burrells, Williams, Southgate, & Crampton, 1999). Intestinal inflammation was assessed using an ordinal scoring system (Table 2) based on lamina propria thickness and cellularity, submucosal connective tissue width, and leukocyte distribution (Barnes et al., 2014; Colburn et al., 2012; Knudsen, Urán, Arnous, Koppe, & Frøkiær, 2007).

Data were analyzed using the SPSS (9.0) statistical analysis program (SPSS, Chicago Illinois), with significance predetermined at $P < 0.05$. One-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 this experiment, there were no significant differences in gain, percent gain, feed fed, feed conversion ratios, specific growth rates, or percent mortality among the tanks of fish being fed the three different diets (Table 3). Overall mean (\pm SE) feed conversion ratios were not

Table 2. Histological scoring system used on rainbow trout fed fish meal or incremental amounts of bioprocessed soybean meal in diets (Barnes et al., 2014, modified from; Goede & Barton, 1990; Barton et al., 2002)

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.

significantly different at 1.30 (\pm 0.04), 1.14 (\pm 0.03), and 1.25 (\pm 0.07) for the 0%, 60%, and 80% BSM diets, respectively. There was no mortality observed in any treatments.

There were no significant differences among the diets in gain, percent gain, or SGR overall and after the first rearing period (days 31–125). However, during the first rearing period, the fish in the tanks that were fed the reference (fish meal) diet had significantly higher gain, percent gain, and SGR than the fish in the tanks receiving the 80% BSM diet, but were not significantly different than the fish receiving the 60% BSM diet. Mean (\pm SE) percent gain at the end of the first rearing period was 26.3 (\pm 1.7) %, 18.8 (\pm 3.3) %, and 9.9 (\pm 2.6) % for the fish being fed the 0%, 60%, and 80% diets, respectively.

Similarly, there were no significant differences overall in individual fish weight, length, or condition factor (Table 4). However, during rearing period 3, the mean (\pm SE) condition factor of the fish in tanks fed the fish meal reference diet was 1.38 (\pm 0.01), which was significantly different from the fish in tanks being fed the 80% bioprocessed soybean meal diet at 1.28 (\pm 0.02). The condition factor of the fish in the tanks that were fed the 60% BSM was 1.31 (\pm 0.02), which was not significantly different from the other two diets.

Fish receiving the 80% bioprocessed diets had significantly longer dorsal fins than those receiving the 60% diet, but were not significantly different from those fed the reference diet. No significant differences were observed among the dietary treatments for the pectoral and pelvic fin indices. There were also no significant differences in any of the organosomatic indices (HSI, SSI, and VSI), nor any of the histological scores (lamina propria, connective tissue, and vacuoles). Representative images of the distal intestines from fish fed each diet used for the scoring are shown in Figures 1–3.

Table 3. Mean (\pm SE) gain, percent gain, food fed, feed conversion ratio (FCR^a), specific growth rate (SGR^b), and mortality of rainbow trout receiving fish meal or incremental levels of bioprocessed soybean meal (BSM) as the main protein ingredient. Overall means with different letters in the same row differ significantly ($P < 0.05$)

Diet		1	2	3
BSM (%)		0	60	80
Initial				
	Start weight (g)	772.7 \pm 44.5	811.1 \pm 29.3	761.5 \pm 71.2
Days 1–30				
	End weight (g)	974.0 \pm 44.4	965.4 \pm 54.7	837.3 \pm 80.1
	Gain (g)	201.2 \pm 4.2 z	154.3 \pm 30.0zy	75.8 \pm 21.2 y
	Gain (%)	26.3 \pm 1.7 zy	18.8 \pm 3.3 zy	9.9 \pm 2.6 y
	Food fed (g)	325 \pm 8	300 \pm 22	277 \pm 24
	FCR	1.61 \pm 0.04	2.18 \pm 0.42	4.67 \pm 1.29
	SGR	0.78 \pm 0.05 z	0.57 \pm 0.10zy	0.31 \pm 0.08y
Days 31–61				
	End weight (g)	1368.6 \pm 77.6	1377.8 \pm 100.6	1171.0 \pm 119.1
	Gain (g)	394.6 \pm 53.8	412.5 \pm 52.4	333.7 \pm 49.8
	Gain (%)	40.6 \pm 5.2	42.4 \pm 3.6	39.7 \pm 4.4
	Food fed (g)	483 \pm 39	468 \pm 45	422 \pm 62
	FCR	1.25 \pm 0.09	1.15 \pm 0.09	1.28 \pm 0.08
	SGR	1.13 \pm 0.12	1.18 \pm 0.08	1.11 \pm 0.10
Days 62–92				
	End weight (g)	1805.6 \pm 85.7	1948.6 \pm 215.3	1609.9 \pm 156.5
	Gain (g)	437.0 \pm 17.2	570.7 \pm 120.4	438.8 \pm 51.0
	Gain (%)	32.1 \pm 1.7	40.3 \pm 6.7	37.8 \pm 3.3
	Food fed (g)	631 \pm 45	656 \pm 79	534 \pm 48
	FCR	1.45 \pm 0.11	1.29 \pm 0.26	1.25 \pm 0.14
	SGR	0.93 \pm 0.04	1.12 \pm 0.17	1.07 \pm 0.08
Days 93–125				
	End weight (g)	2538.7 \pm 95.7	2914.7 \pm 317.1	2449.5 \pm 236.6
	Gain (g)	733.1 \pm 14.9	966.2 \pm 1185	839.6 \pm 94.3
	Gain (%)	40.8 \pm 1.7	49.9 \pm 4.0	52.3 \pm 3.4
	Food fed (g)	855 \pm 13	968 \pm 168	866 \pm 95
	FCR	1.17 \pm 0.03	0.98 \pm 0.06	1.04 \pm 0.08
	SGR	1.14 \pm 0.04	1.35 \pm 0.09	1.40 \pm 0.08
Overall (Days 1–125)				
	Gain (g)	1766.0 \pm 70.2	2103.6 \pm 289.0	1688 \pm 178.1
	Gain (%)	230.3 \pm 13.0	256.7 \pm 27.0	222.1 \pm 14.5
	Food fed (g)	2,294 \pm 118	2,391 \pm 304	2,100 \pm 200
	FCR	1.30 \pm 0.04	1.14 \pm 0.03	1.25 \pm 0.07
	SGR	0.95 \pm 0.03	1.01 \pm 0.06	0.93 \pm 0.04
	Mortality (%)	0	0	0

^aFCR = feed conversion ratio = total food fed/total weight gain.

^bSGR = 100 x [(Ln(final weight)—Ln(initial weight))/days]

4. Discussion

The lack of significant differences in gain, percent gain, and feed conversion ratios indicates that at least 80% of the fish meal can be replaced by BSM in adult rainbow trout diets. NRC (2011) states

Table 4. Mean (\pm SE) condition factor (K^a), fin indices^b, hepatosomatic index values (HSI^c), splenosomatic index (SSI^d), viscerosomatic index (VSI^e), and histology scores for lamina propria, connective tissue, and vacuoles of rainbow trout fed one of three diets containing either fish meal or incremental amounts of bioprocessed soybean meal (BSM) as the primary protein source. Means with different letters in the same row differ significantly ($P < 0.05$)

Diet		1	2	3
BSM (%)		0	60	80
Initial				
	Weight (g)	128.8 \pm 7.4	135.2 \pm 4.9	126.9 \pm 11.9
	Length (mm)	210.8 \pm 3.2	217.0 \pm 2.4	210.4 \pm 5.8
	K	1.34 \pm 0.03	1.31 \pm 0.02	1.32 \pm 0.02
Days 1–30				
	End weight (g)	162.3 \pm 7.4	160.9 \pm 9.1	139.6 \pm 13.4
	End length (mm)	228.5 \pm 2.8	231.0 \pm 2.6	221.8 \pm 7.0
	K	1.33 \pm 0.04	1.28 \pm 0.03	1.24 \pm 0.01
Days 31–61				
	End weight (g)	228.1 \pm 12.9	229.7 \pm 16.8	195.2 \pm 19.8
	End length (mm)	252.5 \pm 4.7	256.6 \pm 4.6	244.4 \pm 7.7
	K	1.38 \pm 0.01z	1.31 \pm 0.02zy	1.28 \pm 0.02 y
Days 62–92				
	End weight (g)	301.0 \pm 14.3	324.8 \pm 35.9	268.3 \pm 26.1
	End length (mm)	277.3 \pm 4.4	284.3 \pm 7.5	267.4 \pm 8.4
	K	1.38 \pm 0.02	1.35 \pm 0.04	1.35 \pm 0.02
Days 93–125 (Final)				
	End weight (g)	423.1 \pm 16.0	485.8 \pm 52.9	408.3 \pm 39.4
	End length (mm)	308.4 \pm 3.9	319.8 \pm 10.3	301.1 \pm 9.3
	K	1.41 \pm 0.03	1.42 \pm 0.05	1.44 \pm 0.02
	Pectoral index (%)	10.1 \pm 0.4	10.6 \pm 0.6	11.1 \pm 0.6
	Pelvic index (%)	9.2 \pm 0.2	8.8 \pm 0.3	9.4 \pm 0.4
	Dorsal index (%)	6.4 \pm 0.1zy	5.5 \pm 0.2 y	6.8 \pm 0.4 z
	HSI (%)	1.22 \pm 0.05	1.39 \pm 0.08	1.34 \pm 0.06
	SSI (%)	0.05 \pm 0.00	0.06 \pm 0.01	0.06 \pm 0.01
	VSI (%)	13.0 \pm 0.2	13.1 \pm 0.5	13.7 \pm 1.0
	Lamina propria ^f	1.33 \pm 0.24	1.25 \pm 0.16	1.50 \pm 0.10
	Connective tissue ^f	1.50 \pm 0.10	1.42 \pm 0.21	1.50 \pm 0.17
	Vacuoles ^f	1.92 \pm 0.21	2.00 \pm 0.00	2.00 \pm 0.14

^a $K = 10^5 \times [\text{weight}/(\text{length}^3)]$

^bFin indices = 100 x (fin length/fish length)

^cHSI = 100 x (liver weight/body weight)

^dSSI = 100 x (spleen weight/body weight)

^eVSI = 100 x (visceral weight/body weight)

^fScoring Parameters in Table 2

that most fish species exhibit reduced feed intake for a short period when their diets are changed. The initial rearing performance differences between the fish receiving the fish meal diet compared to the fish receiving the 80% BSM diet could be due to the relative novelty of the 80% diet. Because the pre-trial feed was a commercial diet that did not contain any BSM, the relatively large amount of soy in the 80% fish meal replacement diet likely required an acclimation period.

Figure 1. Distal intestine of rainbow trout receiving the fishmeal control diet.

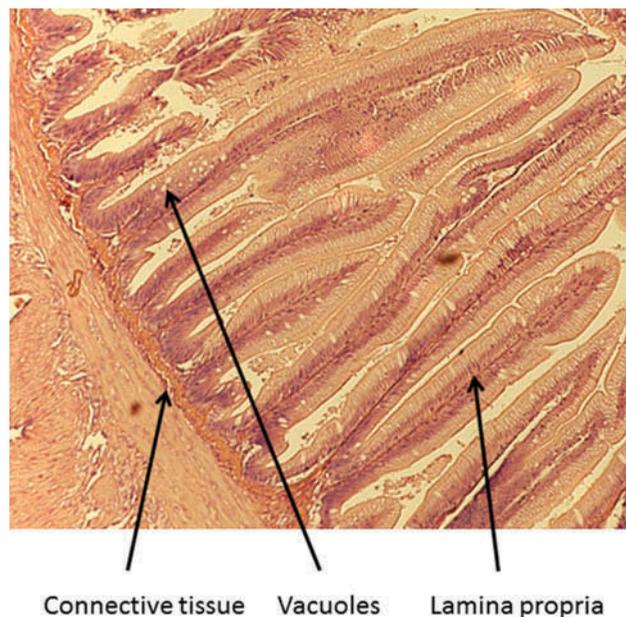
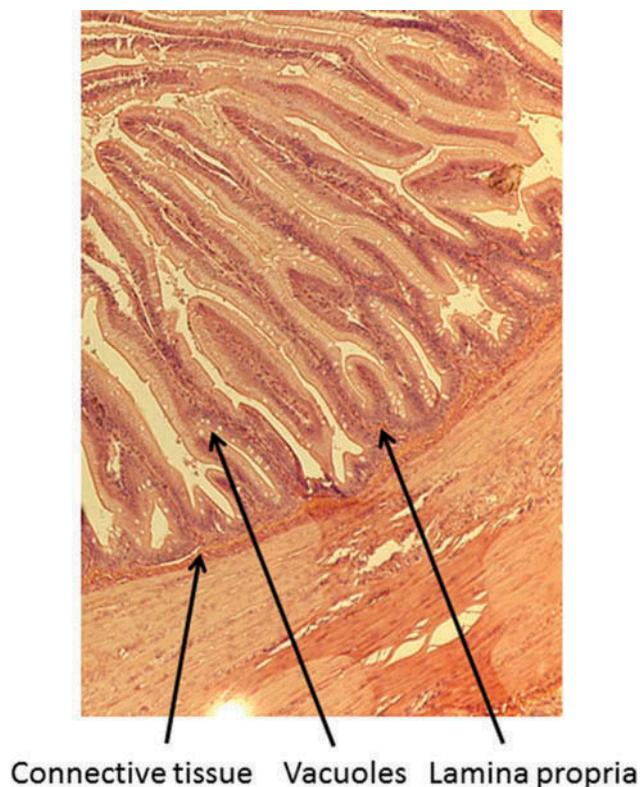
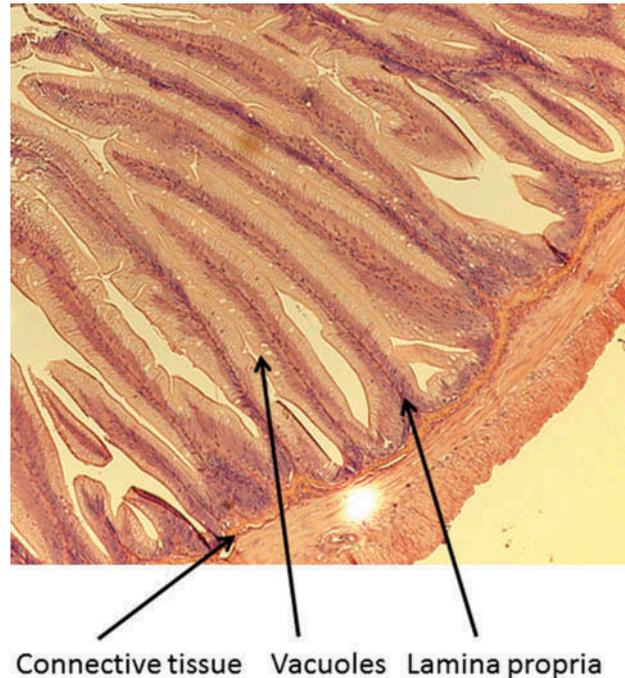


Figure 2. Distal intestine of rainbow trout receiving 60% bioprocessed soybean meal.



The overall results of this study are similar to other experiments feeding BSM to rainbow trout (Barnes et al., 2014, 2015a, 2012, 2013; Bruce et al., 2017a, 2017b; Yamamoto et al., 2010, 2012). Yamamoto et al. (2010, 2012) noted similar results replacing 100% of the fish meal with fermented soybean meal, while Barnes et al. (2012, 2013, 2014, 2015a) found that a maximum of approximately 70% fish meal substitution was possible without any deleterious effects. Bruce

Figure 3. Distal intestine of rainbow trout receiving 80% bioprocessed soybean meal.



et al. (2017a, 2017b) reported a 65% replacement of fish meal by BSM could be attained with no effect on growth. Moniruzzaman et al. (2018) found only 30% of the fish meal could be replaced with fermented protein concentrates. Other species where BSM has been evaluated include: Atlantic cod (*Gadus morhua*) (Refstie et al., 2006; Ringø, Sperstad, Myklebust, Refstie, & Krogh, 2006), Atlantic salmon (*Salmo salar*) (Refstie et al., 2005), black sea bream (*Acanthopagrus schlegelii*) (Azarm & Lee, 2014; Zhou et al., 2011), brown trout (*Salmo salar*) (Sotoudeh, Moghaddam, Shahhosseini, & Aramli, 2016), chinese sucker (*Myxocyprinus asiaticus*) (Yuan et al., 2012), Florida pompano (*Trachinotus carolinus*) (Novriadi et al., 2017), gilthead sea bream (*Sparus aurata* L.) (Kokou, Rigos, Henry, Kentouri, & Alexis, 2012), Japanese flounder (*Paralichthys olivaceus*) (Kader et al., 2012), largemouth bass (*Micropterus salmoides*) (Jiang et al., 2018), orange-spotted grouper (*Epinephelus coioides*) (Shiu et al., 2015), olive flounder (*Paralichthys olivaceus*) (Seong et al., 2018), rockfish (*Sebastes schlegelii*) (Lee, Mohammadi Azarm, & Chang, 2016), white seabass (*Atractosion nobilis*) (Trushenski, Rombenso, Page, Jirsa, & Drawbridge, 2014), whiteleg shrimp (*Litopenaeus vannamei*) (Chiu et al., 2016; Van Nguyen, Hoang, Khanh, Duy Hai, & Hung, 2018), and yellowtail jack (*Seriola lalandi*) (Trushenski et al., 2014).

At 125 days, this experiment should have lasted long enough to determine any differences in fish rearing performance among the diets (Weathercup & McCracken, 1999). NRC (2011) recommends feed trial durations of 56–84 days, with larger fish attaining at least a 200–300% gain. This experiment provided fish weight gains of approximately 250%, thereby meeting both requirements.

The FCR observed in this experiment was slightly higher than that reported in some other experiments involving rainbow trout (Barnes et al., 2012, 2013), but were also similar to other studies (Barnes et al., 2014, 2015a; Bruce et al., 2017b; Yamamoto et al., 2010, 2012). The SGR was slightly lower in this experiment (0.9–1.0) compared to the 1.0 to 1.3 reported by Bruce et al. (2017b) in a similar study, but were extremely low compared to 1.8 to 3.0 reported by Yamamoto et al. (2010, 2012) and Bruce et al. (2017a). The slower growth rate could possibly be due to the size of the fish or water temperatures differences. Yamamoto et al. (2010, 2012) and Bruce et al.

(2017a, 2017b) used juvenile fish, while this study used adult rainbow trout, which have slower growth rates (Stickney, 1994).

The condition factors observed in this experiment were higher than many other rainbow trout experiments (Barnes et al., 2012, 2013, 2014, 2015a, 2015b; Bruce et al., 2017b). This could possibly be because the fish in this experiment were older and larger, and closer to sexual maturity (Barton, Morgan, & Vijayan, 2002).

Relative fin length can be influenced by several factors, including tank-induced abrasions (Bosakowski & Wagner, 1995), rearing unit size and type (Bosakowski & Wagner, 1994), aggressive behavior (Latremouille, 2003), feeding rates (Wagner, Intelmann, & Routledge, 1996), rearing densities (Miller, Wagner, & Bosakowski, 1995; North et al., 2006; Wagner, Jeppsen, Arndt, Routledge, & Bradwisch, 1997), dietary nutritional differences (Kindschi, Shaw, & Bruhn, 1991; Lemm, Rottiers, Dropkin, & Dennison, 1988), environmental stress (Latremouille, 2003), and fish health (Devesa, Barja, & Toranzo, 1989). The lack of difference between the pectoral and pelvic fin indices in this experiment could be attributed to similar environmental stressors and adequate feeding rates. However, the significant difference in dorsal fin relative length between the 60% and 80% BSM may not be biologically different, as both lengths are normal for rainbow trout (Arndt, Routledge, & Wagner et al., 2001, 2002). Kindschi et al. (1991) found a significant difference in the dorsal fin measurement of steelhead trout fed diets containing either menhaden or herring oil. The overall pectoral fin values observed in this experiment are similar to those reported by Parker and Barnes (2015).

The lack of any differences in HSI between the dietary treatments indicates similar energy partitioning. HSI is an indirect measure of glycogen and carbohydrate levels, and can be used to indicate the nutritional state of the fish (Barton et al., 2002; Daniels & Robinson, 1986; Kim & Kaushik, 1992). The HSI levels observed in this study were similar to those reported by Barnes et al. (2013, 2014, 2015b), and slightly higher than those reported by Yamamoto et al. (2010, 2012), Barnes et al. (2012), and Bruce et al. (2017a). Differences in HSI among the studies could be related to fish age. Barton et al. (2002) noted that organosomatic indices can vary depending on life stage, and the rainbow trout used in this study were much larger and older than those used in other experiments.

The VSI indicates how lipids are being used or partitioned with VSI and lipids positively related (Company, Caldach-Giner, Kaushik, & Pérez-Sánchez, 1999; Jobling, Koskela, & Savolainen, 1998; Yildiz, Sener, & Timur, 2006). Thus, similar VSI values among the dietary treatments are likely due to similar dietary lipid levels. At 13.0 to 13.7 the VSI values are similar to the 12.0 to 13.8 values reported by Barnes et al. (2014, 2015a), but higher than those reported by Barnes et al. (2013, 2015b), Parker and Barnes (2014, 2015), Kientz and Barnes (2016), and Bruce et al. (2017a).

SSI measures both immune status and hematopoietic capacity of fish (Barton et al., 2002; Smith, 1991). Similar SSI values indicate that fish health was likely unaffected by dietary treatment. The SSI values observed were within the range reported by other studies (Bruce et al., 2017b; Kientz & Barnes, 2016; Parker & Barnes, 2015).

Enteritis was not observed in this study, despite the well-documented and potentially negative effects of soybean products to the distal intestine of rainbow trout (Romarheim et al., 2008; Merrifield, Dimitroglou, Bradley, Baker, & Davies, 2009; Sealey, Barrows, Smith, Overturf, & LaPatra, 2009). The BSM used in this study likely decreased or eliminated the saponins (Krogdahl et al., 2015) and other antinutritional factors responsible for such enteritis (Barnes et al., 2012, 2013; Yamamoto et al., 2010, 2012). The absolute intestinal scores observed in this study tended to be lower than those reported by Barnes et al. (2014, 2015a, 2015b) for rainbow trout fed different fermented soybean meal diets. This could be due to the dietary differences among the studies or scoring difference between readers.

In conclusion, this study indicates that at least 80% of the dietary fish meal can be directly replaced by BSM in diets of adult rainbow trout. It is unknown if the suitability of dietary BSM extends further during the trout life cycle, prior to spawning. Additional research is needed to determine if this BSM can replace all of the fish meal in adult rainbow trout diets.

Abbreviations: bioprocessed soybean meal (BSM), feed conversion ratio (FCR), specific growth rate (SGR), centimeter (cm), millimeter (mm), milligram (mg), gram (g), kilogram (kg), degree Celsius (°C), Fulton's condition factor (K), standard error (SE), analysis of variance (ANOVA), hepatosomatic index (HSI), splenosomatic index (SSI), viscerosomatic index (VSI), second (s), liter (L), parts per million (ppm), Calcium Carbonate (CaCO₃), tricaine methanesulfonate (MS-222)

Acknowledgements

Thanks to Cody Treft, Tabor Martin, Brian Fletcher, Patrick Nero, Eric Krebs, and the numerous hatchery interns who assisted with this study. The South Dakota Cooperative Fish and Wildlife Research Unit is jointly sponsored by the US Geological Survey, South Dakota Department of Game, Fish and Parks, South Dakota State University, the Wildlife Management Institute, and the US Fish and Wildlife Service. Any use of trade names is for descriptive purposes only and does not imply endorsement by the US Government.

Funding

The authors received no direct funding for this research.

Competing Interests

The authors declare no competing interests.

Conflict of Interest and Ethical Approval

The authors state that they have no conflict of interest. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed by the authors.

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Citation information

Cite this article as: Bioprocessed soybean meal replacement of fish meal in rainbow trout (*Oncorhynchus mykiss*) diets, Jill M. Voorhees, Michael E. Barnes, Steven R. Chipps & Michael L. Brown, *Cogent Food & Agriculture* (2019), 5: 1579482.

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