Iranian Journal of Fisheries Sciences 19(3) 1500-1516 2020
DOI: 10.22092/ijfs.2020.120754

Apparent digestibility coefficients of crude protein, amino acids, crude lipid, dry matter and gross energy of ten feedstuffs for yearling Siberian sturgeon (*Acipenser baerii*, Brandt 1869)

Mirzakhani M.K.[1]; Abedian Kenari A.[1*]; Motamedzadegan A.[2]; Banavreh A.[3]

Received: July 2019 Accepted: September 2019

Abstract

Apparent digestibility coefficients (ADCs) of ten feedstuffs were investigated in yearling Siberian sturgeon, *Acipenser baerii*, (290±22 g), using 1% chromic oxide as the inert marker. The ingredients included: fish (*Clopeonella* sp) meal (FM), meat and bone meal (MBM), poultry by-product meal (PBM), spray-dried blood meal (BM), feather meal (FeM), solvent extract soybean meal (SBM), canola meal (CM), corn gluten meal (CGM), wheat gluten meal (WGM) and bakers' yeast (BY). ADC values of crude protein varied from 60% to 92.9% (FeM and FM, respectively). ADC_{CP} of FM, MBM, PBM (animal origin), WGM, and CGM (plant origin) were significantly higher than the other treatments ($p<0.05$). ADCs of amino acid in feedstuffs followed a similar trend to the ADC_{CP}, but it is not thoroughly correspondence with protein digestibility. The lowest dry matter (65.5%), and lipid (64.8%) digestibility were recorded in BM and FeM, respectively. The WGM (81.5%) exhibited the highest digestibility of gross energy (ADC_{GE}); the lowest was in CM (68.1%). According to the results of this research, FM, MBM, PBM (animal origin) and also WGM and CGM (plant origin) were the more digestible feed ingredients for yearling Siberian sturgeon.

Keywords: Aquaculture, Digestibility, Fish feeding, Ingredients, Siberian sturgeon.

1-Department of Aquaculture, Natural Resources and Marine Sciences Faculty, Tarbiat Modares University, Noor, , Iran
2-Department of Food Science, Sari University of Agricultural Sciences and Natural Resources, Sari, Iran
3-Department of Fisheries, Faculty of Agriculture and Natural Resources, Science and Research Branch, Islamic Azad University, Tehran, Iran
*Corresponding author's Email: aabedian@modares.ac.ir

Introduction

For aquaculture to satisfy the increased demand for fish farming, continuous research must be conducted to select the appropriate alternative to fish meal. Fish meal (FM) is the most important and one of the most expensive protein sources in the aquaculture-formulated diet. Approximately 20% of the world's fish stock is used only to produce fish meal and fish oil (FAO, 2016). The deterioration of fish meal production has boosted the cost of them; hence, efforts have been made to find alternative protein sources to feed farmed aquatic animals (Quinto *et al*., 2018). Therefore, a suitable feedstuff ingredient has to contain some nutritional properties, including high levels of protein, low levels of anti-nutrients, indispensable amino acids, high digestibility, and acceptable palatability (Francis *et al*., 2001; Gatlin *et al*., 2007; Mirzakhani *et al*., 2018).

The investigation for appropriate ingredients requires precise screening of their potential nutritional value and variability at the industrial level. The nutritional value of the diet composition depends on the digestibility of each of its constituents (Lupatsch *et al*., 1997). Feed manufacturers require adjustable, nutritious, and cost-effective formulations based on the content and availability of feedstuffs (Lemos *et al*., 2009). Consequently, many different types of nutrient sources are required to feed farmed fish to maintain the expected fast growth. The first stage of formulating diet is to determine the digestibility and palatability of feedstuff nutrients. Information on the apparent digestibility coefficients (ADCs) is essential; not only does it promote information to improving the diet for growth, but it also restricts contamination through fish production (Chi *et al*., 2017; Karapanagiotidis *et al*., 2019).

In recent years, sturgeon farming has been expanding worldwide, due to the precious eggs (caviar) and meat. Thus, the improvement of sturgeon aquaculture production would be the most reasonable and rational alternative strategy to alleviate the fishing pressure on the natural stocks of sturgeon species (Banavreh *et al*., 2018; Bronzi *et al*., 2011).

Siberian sturgeon is considered as an important cultured sturgeon worldwide (Babaei *et al*., 2011; Sharif Rohani *et al.,* 2017; Falahatkar, 2018) and has been used as a biological model to initiate studies on nutrition since the 1980s (Fontagné-Dicharry *et al*., 2018). Moreover, despite significant global interest in sturgeon aquaculture, there is still a scarcity of information on sturgeon nutrient requirements, and the success in culturing these species of fish needs this information essentially.

Many relatively low-priced animal and plant-based feedstuffs are available, that can replace fish meal in Siberian sturgeon diets, and the investigation for suitable and cost-effective protein alternatives is ongoing. In our previous study (Mirzakhani *et al*., 2018), protein digestibility (*in vivo*) and degree of protein hydrolysis (DPH: *in vitro* pH-stat assay) of ten selected feedstuffs for yearling Siberian sturgeon were investigated. Correlation between the

[DOR: 20.1001.1.15622916.2020.19.3.39.5]

results of *in vitro* and *in vivo* was determined to evaluate the protein quality of ingredients. The rest of the previous study, the present investigation aims to evaluate the apparent digestibility coefficients (ADCs) of crude protein, lipid, energy, and amino acids in 10 animal and plant ingredients for yearling Siberian sturgeon.

Materials and methods

Diet preparation

The current investigation, ten different sources of feedstuff in Siberian sturgeon diets evaluated. Aquafeeds ingredients include fish (*Clopeonella* sp) meal (FM), meat and bone meal (MBM), poultry by-product meal (PBM), spray-dried blood meal (BM), feather meal (FeM), solvent extract soybean meal (SBM), canola meal (CM), corn gluten meal (CGM), wheat gluten meal (WGM), bakers' yeast (BY). An approximation analysis of all feedstuff ingredients are shown in Table 1. The feed constituents pounded for homogeneity (<500 µm) and thoroughly mixed (Chega Co., Isfahan, Iran) with fish oil before water is added to produce stiff dough (Gatlin, 2010). Then, the experimental diet was formulated with each of the feedstuffs using a 70:30 (dry weight basis) from the reference diet (Table 2) with the Lindo program (6.1, Chicago, USA) (Mirzakhani *et al*., 2018). Diets were pressure-pelleted using a meat grinder (CGT Company, 2mec, Italy) with a 3 mm die and placed into a hot air oven (Hootakhsh, Tehran, Iran) at 40 °C for 18 h to attain a moisture content of less than 100 g kg^{-1}. The dried diets were kept at −20 °C until used (Banavreh *et al*., 2019).

Table 1: Proximate composition (%) and gross energy content (Kj g^{-1}) of ingredients.

Ingredient[a]	Moisture (%)	Crude protein (%)	Crude Lipid (%)	Ash (%)	Carbohydrate[b] (%)	Gross energy[c] (Kj g^{-1})
Fish meal (*Clopeonella* sp)	7.1	74.5	6.7	9.7	2	20.4
Meat and Bone meal	7.4	53.1	12	14.9	12.6	19.4
Poultry by-product meal	7	64.5	8.7	10	9.8	20.4
Blood meal	4	88.3	2.2	3.6	1.8	22
Feather meal	6.5	78.1	6.8	3.5	5	23
Soybean meal	9.3	41.9	1.7	6.9	40.2	17.5
Canola meal	11.8	30.6	3.3	8	46.6	16.6
Corn gluten meal	5.7	76.8	4	1.7	11.8	21.7
Wheat gluten meal	4.8	84.3	1.8	1.5	7.7	21.9
Bakers' yeast	6.2	41.3	1.6	1.9	48.9	18.8

[a] Mazandaran Animal and Aquatic feed (Manaqua) Co. Iran
[b] Carbohydrates were calculated by difference. Carbohydrate=100-(crude protein+crude lipid+ash+moisture).
[c] Estimated energy was calculated based on 1 g crude protein being 23.6 Kj, 1 g crude fat being 39.5 Kj and 1 g carbohydrate being 17.2 Kj.

Table 2: Formulation and proximate composition of the reference diet used to measure apparent digestibility (APD) of test ingredients.

Test ingredients	$g\ kg^{-1}$
Fish meal[a]	350
Soybean meal[a]	270.7
Wheat flour[a]	181.1
Soy bean oil[a]	55
Fish oil[b]	55
Lecitine[c]	10
Dicalsium phosphate[a]	5
Mineral mix[d]	20
Vitamin mix[e]	40
BHT[f]	0.2
Choline chloride[a]	3
Cr_2O_3[g]	10
Proximate composition	
Moisture (%)	9.06
Crude protein (%)	40.45
Lipid (%)	14.55
Ash (%)	10.98
Carbohydrate (%)[h]	24.95
Gross energy (Kj g^{-1})[i]	19.58

[a]Kilka (*Clopeonella* sp) meal (Mazandaran Animal and Aquatic feed (Manaqua) Co. Iran)
[b]Kilka oil (Manaqua Co. Iran)
[c]Soybean lecithin with phosphatidyl choline (Behpak company, Iran)
[d]Mineral mix provided (mg Kg^{-1}): Fe: 6000, Cu: 600, Mn: 5000, Zn: 10,000, I: 600, Se: 20, Co: 100, choline chloride: 6000, Career up to 1 kg
[e]Vitamin mix provided (Unit Kg^{-1}): A: 1,200,000 IU, D3: 400,000 IU, E: 50,000 mg, K3: 800 mg, B9: 1000 mg, C: 30,000 mg, B1: 2500 mg, B2: 4000 mg, B6: 25,000 mg, B12: 8 mg, Biotin: 150 mg, Niacin: 35,000 mg and Inositol: 50,000 mg Career up to1 kg
[f]Antioxidant (Gluba Tiox, French)
[g] Chromic oxide (Sigma-Aldrich®, USA)
[h]Carbohydrates were calculated by difference. Carbohydrate =100-(crude protein+crude lipid +ash+moisture)
[i]Estimated energy was calculated based on 1 g crude protein being 23.6 Kj, 1 g crude fat being 39.5 Kj and 1 g carbohydrate being 17.2 Kj.

Experimental fish

Yearling Siberian sturgeons were obtained from the International Sturgeon Research Institute (Guilan province, Iran). They were acclimated in fiberglass tanks (350-L) and were fed the reference diet for one week before the experiment. Fish (n=198) weighing 290±22 g were then distributed randomly into 33 circular fiberglass tanks at a stocking density of 6 fish per tank. Each treatment comprises three replicates (18 fish per treatment). The flow-through water (4.5 L min^{-1}) was used from spring water during the experiments. Fish were fed with experimental diets three times a day (at 08:00, 12:00, and 16:00) to available *ad libitum*. The feeding trial was carried out using the experimental diets under a 12-hr:12-hr light: dark cycle condition for 11 days. During the experiment, water quality consisting of water temperature, dissolved oxygen, pH value was 21±2 °C, 7.1±0.5 mg L^{-1}, and 7-8, respectively.

Digestibility

During the food processing, the amount of 10 g kg^{-1} chromic oxide (Cr_2O_3, Sigma-Aldrich®) as an inert marker was added to the apparent digestibility

[DOR: 20.1001.1.15622916.2020.19.3.39.5]

coefficients determination. The fish were hand feed with experimental diets for 11 days to the contents of the alimentary tract are completely evacuated from previous foods. From day 12, feces samples were collected from all fish in separate tanks by hand stripping 6 hr postprandial, mixed as a pooled sample, and then stored in a freezer (−20 °C) until further analysis. The aforementioned procedure was as long as the sample is provided sufficiently for analysis. To prevent contamination, the fish were first tranquilized with MS_{222} (100 ppm), and the region around the anus was dried with a clean towel before the feces samples were collected (Banavreh *et al*., 2018). Frozen (-20 °C) fecal samples were lyophilized, finely ground, and stored at −20 °C until further analyses. The concentration of chromic oxide in diets and feces was determined by atomic absorption spectrophotometry (Williams *et al*., 1962). The ADCs for test and reference diets were calculated as (Lemos *et al*., 2009; Liu *et al*., 2009; Tibbetts *et al*., 2011).

ADC (%)=100–(100×% Cr_2O_3 in diet/ Cr_2O_3 in feces×% nutrient in feces/ nutrient in diet)

The ADC for the test ingredients was calculated by (Lemos *et al*., 2009; Tibbetts *et al*., 2011):

ADC of test ingredient (%)=ADC test diet+(ADC test diet–ADC reference diet)×(0.7× Dref /0.3×Dingr)

Where Dref=% nutrient of reference diet; Dingr=% nutrient of test ingredient.

Proximate chemical analysis

Chemical composition (crude protein, lipid, moisture, and ash) of the feed ingredients, diets and feces were analysed according to AOAC (2005) producers: total protein content (N×6.25) using an automatic Kjeldahl system (230-Hjeltec Analyzer; Foss Tecator, Hoganas, Sweden), total lipid with an automatic Soxhlet system (2050-FOSS; Sweden) by chloroform extraction, moisture was determined by drying at 105 °C for 24 h in an oven (D-63450; Heraeus, Hanau, Germany), ash by burning in a muffle furnace (Isuzu, Tokyo, Japan) at 550 °C for 6 h.

For each of the feedstuffs, diets, and feces, the total amino acid composition determined. Samples were hydrolyzed in 6 N HCl for 24 hr at 110°C; then, samples derivatized with o-phthaldialdehyde (OPA) (Antoine *et al*., 1999). That was a two-step method of digestion and derivation. Finally, HPLC (Knauer, Berlin, Germany) was used to identify individual amino acids based on comparison with known standards (Oujifard *et al*., 2012).

Statistical analysis

After confirming the homogeneity of variance and normality of the data using Leaven and Kolmogorov-Smirnov tests, respectively, one-way ANOVA was used to compare the treatments. Duncan's multiple range tests were applied to compare significant differences among the treatments (p<0.05) with SPSS™ version 17 (Texas State University, San Marcos, TX, USA).

[DOR: 20.1001.1.15622916.2020.19.3.39.5]

Results

The crude protein and crude lipid content of the heterogeneous groups of feedstuff are presented in Table 1. BM had the highest crude protein content (88.3%); Baker's yeast had the lowest (41.3%). The highest crude lipid content was in PBM (8.7%); the lowest was in WGM and Baker's yeast (1.8% and 1.6%). The ash of the feedstuffs varied from 14.9% (MBM) to 1.5% (WGM). The highest of the carbohydrate (46.6%) was in CM, followed by SBM (40.2%). The highest of the gross energy content (21.9 Kj g^{-1}) was in WGM; the lowest was in CM (16.6 Kj g^{-1}). The reference diet ingredient (CP: 40.45% and CL: 14.55%) presented in Table 2. Proximate composition and gross energy content of the reference diets were showed in Table 3.

Table 3: Proximate composition (%) and gross energy content (Kj g^{-1}) of the reference and test diets[a] used to determination of digestibility coefficients for Siberian sturgeon (*Acipenser baerii*).

Diets	Moisture (%)	Crude protein (%)	Crude Lipid (%)	Ash (%)	Carbohydrate[b] (%)	Gross energy[c] (Kj g^{-1})
Reference	9.06	40.45	14.55	10.98	24.96	19.58
Fish meal (*Clopeonella* sp)	7.36	52.06	12.17	11.14	17.36	20.08
Meat and Bone meal	9.74	43.03	12.86	12.56	21.38	18.91
Poultry by-product meal	8.16	46.46	13.28	10.42	21.33	19.88
Blood meal	8.06	53.34	12.32	8.64	17.65	20.49
Feather meal	7.68	52.43	12.23	9.12	18.47	20.39
Soybean meal	9.04	40.96	11.82	9.72	28.37	19.21
Canola meal	9.82	36.28	12.67	10.81	30.38	18.79
Corn gluten meal	7.46	52.14	11.86	8.24	20.35	20.5
Wheat gluten meal	6.71	53.38	11.19	7.92	20.58	20.58
Bakers' yeast	8.96	40.5	11.84	8.54	30.07	19.41

[a] Test diets (70% reference diet+30% test ingredient)

[b] Carbohydrates were calculated by difference. Carbohydrate =100-(crude protein+crude lipid +ash+moistur).

[c] Estimated energy was calculated based on 1 g crude protein being 23.6 Kj, 1 g crude fat being 39.5 Kj and 1 g carbohydrate being 17.2 Kj.

The lowest concentration of Lys amino acid was found in CGM (4.9%) WGM (5.1%), PBM and CM (5.2%) (Table 4), and the highest value observed in FM (21.2%). The sulfur amino acid, such as Met in FM (23.8%), was found in high concentration. Also, the lowest Lys and Met in the test diets were observed in PBM (7.8% and 6.9%, respectively) (Table 5).

[DOR: 20.1001.1.15622916.2020.19.3.39.5]

Table 4: Amino acids composition of the test ingredients for Siberian sturgeon (*Acipenser baerii*; g kg^{-1}).

Essential amino acids	Test ingredients[a]									
	FM	**MBM**	**PBM**	**BM**	**FeM**	**SBM**	**CM**	**CGM**	**WGM**	**BY**
Arg	48.9	32.5	36.6	51.2	57.1	24.4	16.8	25.2	36.5	17.9
His	11.2	3.6	4.2	29.6	7.3	6.2	4.9	9.5	12.5	4.9
Leu	69.1	43.2	50.7	92.8	69.1	34.9	25.6	93.6	83.7	33.4
Ile	50.3	29.1	33.9	42.2	45.5	26.4	16.8	42.8	53.6	25.6
Val	66	52.2	60.8	89.6	66.5	32.1	27.4	57.7	65.4	34.1
Lys	21.2	6.4	5.2	26.9	18.2	7.6	5.2	4.9	5.1	11.1
Met	23.8	4.1	3.3	6.7	10.9	3.3	2.9	15.7	18.5	2.9
Thr	93.4	11.1	60.7	13.3	49.5	3.2	2.3	8.1	12.6	8.6
Phe	29.6	18.4	22.3	45.3	50.6	14.5	10.9	41.0	50.1	15.1
Non-essential amino acids										
Ala	53.6	37.0	41.3	88.4	45.1	16.9	19.7	88.3	38.3	32.7
Asp	64.4	44.8	52.7	68.6	62.3	45.3	22.7	56.8	44.8	43.2
Glu	76.8	55.1	64.9	67.6	82.1	77.7	51.8	123.9	171.4	58.2
Gly	22.3	86.5	83.4	89.3	72.7	55.7	35.7	67.0	87.9	47.5
Ser	53.4	69.2	70.3	69.5	90.9	30.7	23.5	67.0	88.8	35.0
Tyr	23.2	12.0	14.6	23.9	22.1	10.5	7.1	30.4	30.6	10.1
Total amino acids	707.2	504.1	594.9	814.9	749.9	389.4	273.3	731.9	799.8	380.3

Arg, arginine; His, histidine; Leu, leucine; Ile, isoleucine; Val, valine; Lys, lysine; Met, methionine; Thr, threonine; Phe, phenylalanine; Ala, alanine; Asp, aspartic acid; Glu, glutamic acid; Gly, glycine; Ser, serine; Tyr, tyrosine;
FM, fish (Clopeonella) meal; MBM, meat and bone meal; PBM, poultry by-product meal; BM, spray-dried blood meal; FeM, feather meal; SBM, Soybean meal; CM, canola meal; CGM, corn gluten meal; WGM, wheat gluten meal; BY, bakers' yeast
[a] Mazandaran Animal and Aquatic feed (Manaqua) Co. Iran

Table 5: Amino acids composition of diets for Siberian sturgeon (*Acipenser baerii*; g kg^{-1}).

Essential amino acids	Test diets[a]										
	RD	**FM**	**MBM**	**PBM**	**BM**	**FeM**	**SBM**	**CM**	**CGM**	**WGM**	**BY**
Arg	23.7	18.1	21.8	27.2	30.3	32.6	23.9	21.6	24.7	27.2	21.5
His	5.6	7.1	4.9	5.3	12.4	5.7	5.8	5.5	7.5	7.9	5.6
Leu	33.6	37.9	33.3	38.1	51.9	42.3	24.6	30.9	52.1	49.1	33.2
Ile	24.7	34.3	24.4	26.9	28.4	29.9	25.2	22.3	30.8	32.8	25.3
Val	31.8	39.8	35.6	41.2	45.2	42.6	31.9	30.5	39.4	41.3	32.3
Lys	9.7	13.9	8.9	7.8	15.3	11.7	9.1	8.4	8.1	8.5	10.1
Met	9.3	13.1	7.4	6.9	7.9	9.3	7.5	7.4	11.4	11.8	7.5
Thr	33.7	51.1	27.2	41.2	26.3	37.8	24.6	24.2	26.6	27.6	26.4
Phe	10.8	15.8	13.3	13.1	20.7	21.5	11.9	11.2	21.6	23.5	12.4
Non-essential amino acids											
Ala	23.3	36.6	27.1	28.2	40.6	28.8	21.7	22.0	43.9	28.7	25.3
Asp	34.7	47.9	37.4	39.4	41.4	43.4	38.7	31.2	44.1	36.7	36.6
Glu	58.9	62.7	54.6	58.6	59.5	62.3	63.7	56.5	80.8	90.6	59.2
Gly	22.8	25.3	42.3	40.3	41.8	37.4	33.4	27.1	19.2	41.9	31.0
Ser	27.1	35.6	35.5	38.6	37.6	45.2	28.7	25.7	22.1	46.5	29.8
Tyr	10.9	16.2	10.9	11.3	13.5	14.1	10.9	9.9	19.6	17.1	10.9
Total amino acids	360.6	455.4	384.6	424.1	472.8	464.6	361.5	334.4	451.9	491.3	367.1

Arg, arginine; His, histidine; Leu, leucine; Ile, isoleucine; Val, valine; Lys, lysine; Met, methionine; Thr, threonine; Phe, phenylalanine; Ala, alanine; Asp, aspartic acid; Glu, glutamic acid; Gly, glycine; Ser, serine; Tyr, tyrosine;
RD, reference diet; FM, fish(Clopeonella)meal; MBM, meat and bone meal; PBM, poultry by-product meal; BM, spray-dried blood meal; FeM, feather meal; SBM, Soybean meal; CM, canola meal; CGM, corn gluten meal; WGM, wheat gluten meal; BY, bakers' yeast
[a] Test diets (70% reference diet + 30% test ingredient)

The values of ADCs for crude protein, crude lipid, gross energy, and dry matter of the feedstuffs are displayed in Table 6. The digestibility of dry matter fluctuated from 65.6% (BM) to 84.3% (FM). ADC values of dry matter of FM, MBM, PBM, SBM, CGM, and WGM were significantly higher than those of BM, FeM, CM, and BY (p<0.05). ADC_{CP} value of FM (92.9%) was significantly higher than for other ingredients (p<0.05), while lowest ADC_{CP} was showed in FeM and CM (p<0.05). ADC_{CP} lower than 70% were found in BM (68.5%), SBM (66.2%), BY (66%), CM (61%), and FeM (60%). Also, CGM (74.3%), WGM (76.9%), PBM (83.1%) and MBM (85.6%), were the feedstuffs that indicated ADC_{CP} higher than 70%. ADC_{CP} of FM, MBM, PBM (animal origin), WGM, and CGM (plant origin) were significantly higher than those of other feedstuffs (p<0.05). ACD_{CL} of FeM (64.8%) was significantly lower than other feedstuffs (p<0.05), and FM, MBM, PBP, BM, CGM, WGM, and Bakers' yeast showed significant higher ADC_{CL} than FeM (64.8%). ADC_{GE} of animal feedstuffs such as FM (88.7%) was significantly the other feedstuffs (p<0.05) and followed by PBP (78.4%), BM (72.1%), MBM (71.8%), and Bakers' yeast (76.7%). In the plant feedstuffs, WGM (81.5%) and CGM (80.4%) were higher significant SBM (73.3%) and CM (68.1%).

Table 6: Apparent digestibility coefficients of dry matter, crude protein, crude lipid and gross energy in the test ingredients for Siberian sturgeon (*Acipenser baerii*) .

Ingredient	ADC_{DM}	ADC_{CP}	ADC_{CL}	ADC_{GE}
Fish meal (*Clopeonella* sp)	84.3±1.3^{a}	92.9±1.3^{a}	89.7±0.6^{a}	88.7±0.6^{a}
Meat and Bone meal	80.4±1.1^{b}	85.6±0.9^{b}	81.1±0.8^{b}	71.8±1.6^{cd}
Poultry by-product meal	81.7±0.5^{b}	83.1±0.8^{b}	78.1±1.2^{c}	78.4±1.1^{b}
Blood meal	65.6±0.8^{d}	68.5±0.4^{d}	69.1±0.6^{d}	72.1±0.9^{cd}
Feather meal	67.6±0.4^{d}	60±1.0^{e}	64.8±0.8^{e}	74.5±1.8^{c}
Soybean meal	83.3±1.1^{a}	66.2±1.7^{d}	66.9±0.6^{de}	73.3±0.3^{c}
Canola meal	76.4±1.5^{c}	61.0±2.6^{e}	66.3±0.8^{de}	68.1±1.6^{d}
Corn gluten meal	81.1±0.6^{b}	74.3±2 ^{c}	77.1±1.3^{c}	80.4±1.4^{b}
Wheat gluten meal	82.3± 1.3^{ab}	76.9±1.3^{c}	76.1±0.2^{c}	81.5± 1.7^{b}
Bakers' yeast	82.1±0.8^{ab}	66.0±3^{d}	67.1±0.2^{d}	76.7±1.1^{bc}

ADC_{DM}, apparent digestibility coefficient of dry matter; ADC_{CP}, apparent digestibility coefficient of crude protein; ADC_{CL}, apparent digestibility coefficient of crude lipid; ADC_{GE}, apparent digestibility coefficient of gross energy.

Mean±SE (n=2); values within the same column with different superscript letters are significantly different (p<0.05).

ADCs for nine essential amino acids (EAAs) and six non-essential amino acids (NEAAs) in test ingredients were shown in Table 7. The Lys and Met value of FM were significantly higher than the PBM, BM, FeM, SBM, CM, CGM, WGM, and BY (p< 0.05). Based on data from Table 7, the lowest digestibility of ΣEAAs and ΣNEAAs of animal-origin was observed in the FeM. The highest value of the digestibility of ΣEAAs and ΣNEAAs in plant feedstuffs was observed in CG, followed by WG and the lowest in CM.

[DOR: 20.1001.1.15622916.2020.19.3.39.5]

Discussion

Nowadays, in aquaculture, there are many efforts to replace the aquafeed protein from ingredients that are continuously available and relative to the low cost (Gatlin *et al*., 2007; Dadgar *et al*., 2010; Dadgar *et al*., 2014). Ascertaining the digestibility coefficient is an imperative necessity to screen potential feed ingredients for formulating nutritious feed for a species (Jannathulla *et al*., 2018). Factors such as the type of feed production (extruded and pelletized), ANFs in feedstuffs such as fiber, which increase the intestinal evacuation rates and trypsin inhibitor, phytic acid, tannin, saponin, glucosinolate, reduce ADCs and conclusively reduces the growth (Becker and Makkar, 1999; Mandal and Ghosh, 2010; Safari *et al*., 2016; Banavreh *et al*., 2018; Jannathulla *et al*., 2018).

The present results indicated that the highest value of ADC_{DM} was observed in the diets containing FM (84.3%) and SBM (83.3%). In this frame, Liu *et al*. (2009) stated that the ADC_{DM} (ICP-AES chromic oxide analyses method) of FM and SBM in juvenile Siberian sturgeon (8.38±0.20 g) was 79.9% and 76.9%, respectively. A comparison of these findings shows that the ADC_{DM} of these two feedstuffs in the Siberian sturgeon improves with the increasing fish weight. This can be due to the improvement of digestive enzymes; however, the lowest value obtained in BM (65.6%) and FeM (67.7%). Liu *et al*. (2009) postulated that the ADC_{DM} value of FFeM (Fermented feather meal) and HFeM (Hydrolysed feather meal) in juvenile Siberian sturgeon was 82.6% and 77.2%, respectively. Improving the digestibility of ADC_{DM} value in Liu *et al*. (2009) study can be attributed to the biotechnological processes, such as fermentation and hydrolysis because it breaks macronutrients and enhances the digestibility of the feedstuff. Differences in ADC_{DM} of high-carbohydrate plant feedstuffs can result from differences in the chemical composition of starch in plant products. In this regard, the difference ADC_{DM} value of gluten (wheat and corn) with canola meal was quite tangible. This study showed that the ADC_{DM} of baker's yeast is high, which indicates that yeast carbohydrates lack nonstarch polysaccharide (NSP).

Protein is one of the most important factors in aquafeeds. In the present study, the ADC_{CP} value of the FeM and FM varied from 60% to 92.9%, respectively. The disparity observed in the ADC of crude protein between the ingredients could be ascribed to the variations in protein solubility and dispersibility indices (Jannathulla *et al*., 2018). Meanwhile, Gaylord *et al*. (2008) stated that the ADC_{CP} of FeM in rainbow trout was 87%. The low nutritional value of FeM could be owing to high levels of poorly digestible keratin protein (Tibbetts *et al*., 2011; Mirzakhani *et al*., 2018), the presence of disulfide bonding (Moran *et al*., 1966) and the presence of indigestible amino acid processing products, namely lysinoalanine and lanthionine (Tibbetts *et al*., 2011). Also, the experimental strategy of placing the test ingredient into a reference diet (presently at 30%) resulted in inclusions higher than the recommended levels for many fish species, for ingredients such as blood meal and feather meal and poultry by-product meal (Lemos *et al*., 2009; Tibbetts *et al*., 2011). High dietary levels of some ingredients may produce a decrease in palatability (Gatlin *et al*., 2007) and feed intake, leading to increased metabolic fecal nitrogen and, hence, decreased ADC (Bureau *et al*., 2002; Lemos *et al*., 2009). Brunson *et al*. (1997) suggested that high levels of indigestible material in feedstuffs could have reduced the protein digestibility of these ingredients by decreasing gut transit time and physically guarding protein in the digestive from enzyme degradation.

This study shows that the processed plant proteins (WGM, CGM) have a higher digestibility than untreated plant proteins (SBM and CM). The appearance of antinutritional factors (ANFs) in plant protein can reduce the digestibility of feed ingredients, especially for proteins (Yun *et al*., 2014; Hardy, 2010; Collins *et al*., 2013; Gatlin *et al*., 2007; Jannathulla *et al*., 2018; Ma *et al*., 2018;). Antinutrients in SBM and CM (such as phytic acid, trypsin inhibitor, lectins, saponins, glucosinolates, and fiber) can be decreased the protein digestibility by establishing of complex compounds with proteins, mineral (Becker and Makkar, 1999; Gatlin *et al*., 2007; Ma *et al*., 2018), and interfere with digestive enzymes (e.g., protease, amylase, etc.) (Cheng *et al*., 2010; Safari *et al*., 2016). Additionally, SBM and CM contain a lot of fiber (not measured in our study) that can reduce digestion by fasting the rate of gastrointestinal passage in monogastric animals (Krogdahl *et al*., 2003; Sajjadi and Carter, 2004; Romarheim *et al*., 2006; Nguyen *et al*., 2015; Ren *et al*., 2018).

Liu *et al*. (2009) postulated that the ADC_{CP} values of fish meal (85.4%), meat and bone meal (83.9%), poultry by-product (86.1%), hydrolyzed feather meal (88.2%), fermented feather meal (79.9%), solvent extracted cottonseed meal (83.7%) and soybean meal (91.9%) in *Acipenser baerii* (8.38 g). Organoleptic properties of experimental diets may affect feeding utilization efficiency. The experimental diets of the present study were prepared via the cold pellet method. In this regard, the extrusion technique can positively affect the digestibility and bioavailability of plant-based diets due to high pressure and temperature during processing (Safari *et al*., 2016; Ahmed *et al*., 2018). Also, Bureau *et al*. (1999) acknowledge that the optimization and standardization of the processing conditions in the feather meal lead to improvement of the digestibility of this feedstuff in rainbow trout. The pressure and temperature required for extrusion can be lead to eliminate the antinutrients in plant-based diets. Noncompliance with the digestibility of plant protein sources in our study with Liu *et al*. (2009) research can be due to differences in the food production methods and the fish size.

[DOR: 20.1001.1.15622916.2020.19.3.39.5]

In the present study, the trend of digestibility of EAA and NEAA was similar to that of apparent digestibility coefficients. The average digestibility of EAA and NEAA of FM and FeM was 90.6%, 71.8 %, and 87.9%, 61.6%, respectively. Although the amino acid contents in FM are not the highest among these ingredients, the most individual amino acid in FM had the highest digestibility, which is in line with the results of Liu *et al*. (2009). The highest value of the digestibility of amino acids was related to Arg in FM (94%), which coincided with Chi *et al*. (2017) finding on cobia. The apparent digestibility coefficients of amino acid varied from 64.8% for Lys in WGM to 90.4% for Lys in FM and 68.1% for SBM in Met to 91.1% for FM in Met. Liu *et al*. (2009) corroborated that the digestibility of Lys and Met amino acid for SBM in juvenile Siberian sturgeon was 92.8% and 88.6%, respectively. One of the reasons for this difference can be correlated with the method used to collection faces, which may lead to the estimated nutrient digestibility, be lower than their actual values. However, nutritional studies in fishes showed that ADCs of nutrients in the Guelph system, as one of the fecal collection methods, were 6–10% higher than those in the stripping method (Glencross *et al*., 2007). The stripping methods because the low length of time food remains in the gut can influence its digestibility (Heinitz *et al*., 2016). Specifically, formulate feed and prognostication fish performance, it is essential to base both the commendation and feed formulations on digestible rather than total amino acid contents, particularly in protein arrogate and decrease of aquaculture excretion (Mirzakhani *et al*., 2018).

The deficiency of a digestible EAA will lead to reduced utilization of the dietary protein (Lemme *et al*., 2004; Liu *et al*., 2009). As many modern aquaculture feeds are now is formulated on a digestible amino acid basis (Glencross *et al*., 2007).

ADC_{CL} in the FM diet was well digested (89.7%) by Siberian sturgeon, while the lowest digestibility observed in the FeM (64.8%). Lupatsch *et al*. (1997) stated a strong influence of fatty acid composition, and thus the melting point of the fat on lipid digestibility in gilthead seabream (*Sparus aurata*). The earlier study by Austreng (1978) showed that lipid digestibility coefficients were affected by fatty acid chain length, unsaturated value, the content of incorporation in dietary fat and other fatty acids ratio, and melting point. Fish oil is typically high in polyunsaturated fatty acids (Abedian Kennari *et al.*, 2007), but FeM has saturated fatty acids (fatty acid not assay in this investigation). The findings of our study showed that the ADC_{CL} in plant feedstuffs on the yearling Siberian sturgeon is low, which is consistent with the results of Safari *et al*. (2016) in the great sturgeon (*Huso huso*).

Differences in ADC_{GE} among feedstuffs were similar to differences in ADC_{DM} but tended to be more pronounced. With few exceptions, feedstuffs that differed significantly in ADC_{DM} also differed in ADC_{GE}.

Brunson *et al*. (1997) acknowledged that in aquatic animals, the ADC_{GE} of plant feedstuffs was inversely related to fiber and also in some species to starch content. Fiber encompasses effectively no digestible energy for fishes (monogastric animals), and starches may be digested with diverging levels of efficiency, depending on the chemical composition of the starch and the digestive capability of the species to which it fed. The results of this study showed that ADC_{GE} is low for untreated plant feedstuffs (i.e., CM and SBM) and untreated animal feedstuffs (BM and PBP). Although the energy digestibility of the treated plant feedstuffs proteins (i.e., WGM and CGM), as well as the FM, is high in yearling Siberian sturgeon. The apparent digestibility of the gross energy of bakers' yeast was mid-range in the feedstuffs. Thus significant differences in energy digestibility of feedstuffs that embraced high levels of carbohydrate and low levels of protein and lipid (i.e., CM feedstuff) seemed to be associated with the nature of the starch present rather than its quantity, corroborating results reported by Chu *et al*. (2015).

ADC_{GE} indicated, however, that energy-yielding compounds in animal protein feedstuffs, which are being principally in the form of highly-digestible proteins and lipids, were well utilized by yearling Siberian sturgeon.

Considerable variability in the coefficients of apparent digestibility of dry matter, lipid, protein, and amino acids in ten feedstuffs was determined. These variables should be considered in the substitution of total protein by amino acids for the more realistic and cost-effective formulation of sturgeon feeds. This research shows that there is an appropriate level of essential amino acids (especially lysine and methionine) in the feedstuffs. Still, the digestibility of the essential amino acids in the Siberian sturgeon is low. To more specifically formulate feed, it is essential to base both the commendation and feed formulations on digestible rather protein than total amino acid contents, particularly in protein replacement and reduction of aquaculture excretion. However, in the current trial, animal protein such as FM, MBM, and PBM and plant protein concentrate such as CGM and WGM exhibited high apparent protein digestibility coefficients for yearling Siberian sturgeon (290±22 g). Also, FM and plant protein concentrate (CGM and WGM) displayed high apparent energy digestibility coefficients, when compared to other feedstuffs. It recommended that the pre-processing technique be carried out to improve the digestibility of the feedstuff.

Acknowledgments

The authors would like to give thanks to the Tarbiat Modares University (TMU, Iran) and Iran National Science Foundation (INSF, grant number: 94013788) for their financial supports. Also, we would like to thank Mr. Morteza Kamali for his valuable help.

References

Abedian Kennari, A.M., Oveisipour, M.R. and Nazari, R.M., 2007.

Effects of n3-HUFA enriched *Daphnia magna* on growth, survival, stress resistance, and fatty acid composition of larvae of Persian sturgeon (*Acipenser persicus*). *Iranian Journal of Fisheries Sciences*, 7(**1**), 1-14.

Ahmed, M., Liang, H., Chisomo Kasiya, H., Ji. K., Ge, X., Ren, M. and Sun, A., 2018. Complete replacement of fish meal by plant protein ingredients with dietary essential amino acids supplementation for juvenile blunt snout bream (*Megalobrama amblycephala*). *Aquaculture Nutrition*, 25, 205-214.

Antoine, F.R., Wei, C.I., Littell, R.C. and Marshall, M.R., 1999. HPLC method for analysis of free amino acids in fish using o-phthaldialdehyde precolumn derivatization. *Journal of Agricaltural Food Chemistry*, 47, 5100-5107.

AOAC, 2005. Official Methods of Analysis of AOAC International. 18th ed. (Maryland, USA), pp. 1-68.

Austreng, E., 1978. Digestibility determination in fish using chromic oxide marking and analysis of contents from different segments of the gastrointestinal tract. *Aquaculture*, 13(**3**), 265-272.

Babaei, S.S., Abedian Kenari, A., Nazari, R. and Gisbert, E., 2011. Developmental changes of digestive enzymes in Persian sturgeon (*Acipenser persicus*) during larval ontogeny. *Aquaculture*, 318(**1-2**), 138-144.

Banavreh, A., Soltani, M., Kamali, A., Yazdani Sadati, M.A. and Shamsaie, M., 2018. Effects of olive pomace on growth performance, digestibility, body composition and fatty acid profile in yearling Siberian sturgeon, *Acipenser baerii* (Brandt 1896). *Aquaculture Nutrition*, 25(**2**), 333-342.

Banavreh, A., Soltani, M., Kamali, A., Yazdani-Sadati, M.A. and Shamsaie, M., 2019. Immuno-physiological and antioxidant responses of Siberian sturgeon (*Acipenser baerii*) fed with different levels of olive pomace. *Fish Physiology and Biochemistry*, 45, 1419-1429.

Becker, K. and Makkar, H.P., 1999. Effects of dietary tannic acid and quebracho tannin on growth performance and metabolic rates of common carp (*Cyprinus carpio* L.). *Aquaculture*, 175(**3–4**), 327-335.

Bronzi, P., Rosenthal, H. and Gessner, J., 2011. Global sturgeon aquaculture production: An overview. *Journal of Applied Ichthyology*, 27(**2**), 169-175.

Brunson, J.F., Romaire, R.P. and Reigh, R.C., 1997. Apparent digestibility of selected ingredients in diets for white shrimp *Penaeus setiferus* L. *Aquaculture Nutrition*, 3(**1**), 9–16.

Bureau, D., Bevan, D., Cho, C., Simmons, L., Harris, A. and Azevedo, P., 2002. Feather meals and meat and bone meals from different origins as protein sources in rainbow trout (*Oncorhynchus mykiss*) diets. *Aquaculture*, 181(**3-4**), 281–291.

Cheng, Z., Ai, Q., Mai, K., Xu, W., Ma, H., Li, Y. and Zhang, J., 2010. Effects of dietary canola meal on growth performance, digestion and metabolism of Japanese seabass, *Lateolabrax japonicus*. *Aquaculture*, 305(**1–4**), 102-108.

Chi, S., Wang, W., Tan, B., Dong, X., Yang, Q., Liu, H. and Zhang, S., 2017. The apparent digestibility coefficients of 13 selected animal feedstuff for Cobia, *Rachycentron canadum*. *Journal of the World Aquaculture Society,* 48(**2**), 280-289.

Chu, Z.J., Yu, D.H., Yuan, Y.C., Qiao, Y., Cai, W.J., Shu, H. and Lin, Y.C., 2015. Apparent digestibility coefficients of selected protein feed ingredients for loach *Misgurnus anguillicaudatus*. *Aquaculture Nutrition,* 21(**4**), 425–432.

Collins, S.A., Mansfield, G.S., Desai, A.R., Van Kessel, A.G., Hill, J.E. and Drew, M.D., 2013. Structural equation modeling of antinutrients in rainbow trout diets and their impact on feed intake and growth. *Aquaculture,* 416, 219-227.

Dadgar, S., Saad, C.R., Bin, Alimon, A.R., Kamarudin, M.S. and Nafisi Bahabadi, M., 2010. Comparison of soybean meal and Cottonseed meal variety Pak (CSMP) on growth and feed using in rainbow trout (*Oncorhynchus mykiss*). *Iranian Journal of Fisheries Sciences,* 9, 49-60.

Dadgar, S., Mohd Salleh Kamarudin, M. and Ehteshami, F., 2014. Apparent digestibility coefficients and nutritional value of Iranian cottonseed meal varieties for rainbow trout (*Oncorhynchus mykiss*). *Iranian Journal of Fisheries Sciences*, 13, 522-529.

Falahatkar B., 2018. Nutritional requirements of the Siberian sturgeon: An Updated Synthesis. In: Williot P., Nonnotte G., Vizziano-Cantonnet D., Chebanov, M. (Eds.), The Siberian Sturgeon (*Acipenser baerii*, Brandt 1869) Volume 1-Biology, Chapter 11. Springer International Publishing AG, part of Springer Nature. pp. 207-228.

FAO, Food and Agriculture Organization of the United Nations., 2016. The state of world fisheries and aquaculture 2016. Rome, Italy: FAO Fisheries and Aquaculture Department. pp. 45-51.

Fontagné-Dicharry, S., Larroquet, L., Dias, K., Cluzeaud, M., Heraud, C. and Corlay, D., 2018. Effects of dietary oxidized fish oil supplementation on oxidative stress and antioxidant defense system in juvenile rainbow trout (*Oncorhynchus mykiss*). *Fish and Shellfish Immunology,* 74, 43-51.

Francis, G., Makkar, H.P.S. and Becker, K., 2001. Antinutritional factors present in plant-derived alternate fish feed ingrediants and their effects in fish. *Aquaculture*, 199(**3-4**), 197-227.

Gatlin, D.M., 2010. Principles of fish nutrition. *Southern Regional Aquaculture Center,* 92, 1-8.

Gatlin, D.M., Barrows, F.T., Brown, P., Dabrowski, K., Gaylord, T.G., Hardy, R.W. and Wurtele, E., 2007. Expanding the utilization of

[DOR: 20.1001.1.15622916.2020.19.3.39.5]

sustainable plant products in aquafeeds: A review. *Aquaculture Research*, 38(**6**), 551-579.

Gaylord, T.G., Barrows, F.T. and Rawles, S.D., 2008. Apparent digestibility of gross nutrients from feedstuffs in extruded feeds for rainbow trout, *Oncorhynchus mykiss*. *Journal of the World Aquaculture Society*, 39(**6**), 827–834.

Glencross, B.D., Booth, M. and Allan, G.L., 2007. A feed is only as good as its ingredients - A review of ingredient evaluation strategies for aquaculture feeds. *Aquaculture Nutrition*, 13(**1**),17-34.

Hardy, R.W., 2010. Utilization of plant proteins in fish diets: Effects of global demand and supplies of fishmeal. *Aquaculture Research,* 41(**5**), 770-776.

Heinitz, M.C., Lemme, A. and Schulz, C., 2016. Measurement of digestibility in agastric fish based on stripping method – apparent nutrient, energy and amino acid digestibilities of common feed ingredients for carp diets (*Cyprinus carpio*). *Aquaculture Nutrition*, 22, 1065-1078. DOI:10.1111/anu.12324.

Jannathulla, R., Dayal, J.S., Vasanthakumar, D., Ambasankar, K. and Muralidhar, M., 2018. Effect of fungal fermentation on apparent digestibility coefficient for dry matter, crude protein and amino acids of various plant protein sources in *Penaeus vannamei*. *Aquaculture Nutrition,* 24(**4**), 1318–1329.

Karapanagiotidis, I.T., Psofakis, P., Mente, E., Malandrakis, E. and Golomazou, E., 2019. Effect of fishmeal replacement by poultry by-product meal on growth performance, proximate composition, digestive enzyme activity, haematological parameters and gene expression of gilthead seabream (*Sparus aurata*). *Aquaculture Nutrition*, 25(**1**), 3-14.

Krogdahl, Å., Bakke-McKellep, A.M. and Baeverfjord, G., 2003. Effects of graded levels of standard soybean meal on intestinal structure, mucosal enzyme activities, and pancreatic response in Atlantic salmon (*Salmo solar* L.). *Aquaculture Nutrition,* 9(**6**), 361-371.

Lemme, A., Ravindran, V. and Bryden, W.L., 2004. Ileal digestibility of amino acids in feed ingredients for broilers. *World's Poultry Science Journal,* 60(**4**), 423-438.

Lemos, D., Lawrence, A.L. and Siccardi, A.J., 2009. Prediction of apparent protein digestibility of ingredients and diets by in vitro pH-stat degree of protein hydrolysis with species-specific enzymes for juvenile Pacific white shrimp *Litopenaeus vannamei*. *Aquaculture*, 295(**1-2**), 89–98.

Liu, H., Wu, X., Zhao, W., Xue, M., Guo, L., Zheng, Y. and Yu, Y., 2009. Nutrients apparent digestibility coefficients of selected protein sources for juvenile Siberian sturgeon (*Acipenser baerii* Brandt), compared by two chromic oxide analyses methods. *Aquaculture Nutrition*, 15(**6**), 650–656.

Lupatsch, I., Sklan, D. and Pfeffer, E., 1997. Apparent digestibility coefficients of feed ingredients and their predictability in compound diets for gilthead seabream , *Sparus aurata* L. *Aquaculture Nutrition*, 3, 81–89.

Ma, Z., Hassan, M.M., Allais, L., He, T., Leterme, S., Ellis, A.V. and Qin, J.G., 2018. Replacement of fishmeal with commercial soybean meal and EnzoMeal in juvenile barramundi *Lates calcarifer*. *Aquaculture Research,* 49(**10**), 3258–3269.

Mandal, S. and Ghosh, K., 2010. Inhibitory effect of Pistia tannin on digestive enzymes of Indian major carps: An in vitro study. *Fish Physiology and Biochemistry,* 36(**4**), 1171–1180.

Mirzakhani, M.K., Abedian Kenari, A. and Motamedzadegan, A., 2018. Prediction of apparent protein digestibility by in vitro pH-stat degree of protein hydrolysis with species-specific enzymes for Siberian sturgeon (*Acipenser baeri*, Brandt 1869). *Aquaculture*, 496, 73-78.

Moran, J.E.T., Summers, J.D. and Slinger, S.J., 1966. Keratin as a source of protein for the growing chick. *Poultry Science,* 45(**6**), 1257–1266.

Nguyen, H.P., Khaoian, P., Fukada, H., Suzuki, N. and Masumoto, T., 2015. Feeding fermented soybean meal diet supplemented with taurine to yellowtail *Seriola quinqueradiata* affects growth performance and lipid digestion. *Aquaculture Research*, 46(**5**), 1101–1110.

Oujifard, A., Seyfabadi, J., Abedian-Kenari, A. and Rezaei, M., 2012. Fish meal replacement with rice protein concentrate in a practical diet for the Pacific white shrimp, *Litopenaeus vannamei* Boone, 1931. *Aquaculture International,* 20(**1**), 117–129.

Quinto, B.P.T., Albuquerque, J.V., Bezerra, R.S., Peixoto, S. and Soares, R., 2018. Replacement of fishmeal by two types of fish protein hydrolysate in feed for postlarval shrimp *Litopenaeus vannamei*. *Aquaculture Nutrition*, 24(**2**), 768-776.

Ren, S., Zhu, J., Cai, C., Wang, Z., Wu, P., Wang, Y., Cao, X. and Ye, Y., 2018. Pectin plays a role in restricting the utilization of rapeseed meal by Chinese mitten crab, *Eriocheir sinensis*. *Aquaculture Research,* 50, 611-620.

Romarheim, O.H., Skrede, A., Gao, Y., Krogdahl, Å., Denstadli, V., Lilleeng, E. and Storebakken, T., 2006. 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(**1-4**), 354–364.

Sajjadi, M. and Carter, C.G., 2004. Effect of phytic acid and phytase on feed intake, growth, digestibility and trypsin activity in Atlantic salmon (*Salmo salar* L.). *Aquaculture Nutrition*, 10, 135-142.

Safari, O., Naserizadeh, M. and Mohammadi Arani, M., 2016. Digestibility of selected feedstuffs in subadult Caspian great sturgeon, *Huso huso* using settlement faecal collection and stripping methods. *Aquaculture Nutrition*, 22(**2**), 293–303.

Sharif Rohani, M., Haghighi, M. and Bazari Moghaddam, S., 2017. Study on nanoparticles of *Aloe vera* extract on growth performance, survival rate and body composition in Siberian sturgeon (*Acipenser baerii*). *Iranian Journal of Fisheries Sciences*, 16(**2**), 457-468.

Tibbetts, S.M., Verreth, J.A.J. and Lall, S.P., 2011. *In vitro* pH-Stat protein hydrolysis of feed ingredients for Atlantic cod, *Gadus morhua*. 2. *In vitro* protein digestibility of common and alternative feed ingredients. *Aquaculture*, 319(**34**), 407416.

Williams, C.H., David, D.J. and Iismaa, O., 1962. The determination of chromic oxide in faeces samples by atomic absorption spectrophotometry. *The Journal of Agricultural Science*, 59(**03**), 381-385.

Yun, B., Xue, M., Wang, J., Sheng, H., Zheng, Y., Wu, X. and Li, J., 2014. Fishmeal can be totally replaced by plant protein blend at two protein levels in diets of juvenile Siberian sturgeon, *Acipenser baerii* Brandt. *Aquaculture Nutrition*, 20(**1**), 69-78.