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Tuna by-product meal as a dietary protein source replacing fishmeal in juvenile Korean rockfish *Sebastes schlegeli*

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Abstract

This study was conducted to evaluate the use of tuna by-product meal (TBM) as a substitute for fishmeal in juvenile Korean rockfish (*Sebastes schlegeli*) diets. Five isonitrogenous (52% crude protein) and isocaloric (4.9 kcal/g) diets were prepared. Control diet (Con) was formulated to contain brown fishmeal, whereas 25, 50, 75, and 100% of fishmeal was substituted with the same percentage of TBM in the TBM25, TBM50, TBM75, and TBM100 diets, respectively. Three replicate groups of fish (initial weight, 29.5 ± 0.6 g) were fed one of the five diets for 12 weeks. The mean weight gain of fish fed the Con and TBM25 diets was significantly higher than that of fish fed the TBM100 diet ($P < 0.05$), but it was not significantly different from the weight gain of fish fed the TBM50 and TBM75 diets. The feed efficiency and protein efficiency ratios of fish fed the Con diet were significantly higher than those of fish fed the TBM100 diet ($P < 0.05$), but were not significantly different from those fed the TBM25, TBM50, and TBM75 diets. The TBM25, TBM50, TBM75, and TBM100 diets had significantly ($P < 0.05$) lower incidence cost and higher profit index than the Con diet. These results suggest that the tuna by-product meal used in this study could replace up to 75% of fishmeal protein in the diet without reducing growth and feed utilization in juvenile Korean rockfish weighing 29–53 g. By considering feed cost, the TBM 75 diet is recommendable for Korean rockfish farming.

Keywords: Korean rockfish, *Sebastes schlegeli*, Fishmeal, Tuna by-product meal, Dietary protein, Growth

Background

Fishmeal is the most important protein source for fish culture feed due to its high-protein content and good balance of essential amino acids. In addition, it can improve fish feed palatability. High-quality fishmeal used in Korea is mainly imported from South American countries such as Chile (KITA 2016). Their prices are unstable, generally increasing due to fluctuations of raw fish catches.

Korean rockfish are the most abundant domestic aquaculture species along with flounder (Statistics Korea 2016). Korean rockfish have high dietary protein requirements (Lee et al. 2002). Considerable amounts of protein sources such as fishmeal are needed for rockfish feed. High contents of good quality fishmeal in diets generally result in improved fish growth and feed efficiency

(Vergara et al. 1999). Since fishmeal is expensive ingredients, using large amounts of them in diets can increase feed price. Considering both price and quality of fishmeal, it is very important for efficient fish culture management to use proper fishmeal in diets to reduce feed costs while improving the growth of cultured fish.

Previous studies have examined the use of animal and plant protein source as alternative to fishmeal for Korean rockfish feed (Lim et al. 2004), including the utilization of tuna by-product meal prepared by fermenting a mixture of tuna meal and soybean meal (Jeon et al. 2014).

Nutrient contents in tuna by-product meals such as protein and essential amino acids are slightly lower than those in high-quality fishmeal imported from South America, reflecting economics. Domestic feed companies that produce formulated feeds for Korean rockfish use tuna by-product meal as a portion of dietary protein source. However, there is limited research on the utilization of tuna by-product meal prepared without

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mixing plant protein sources in this species. The present study was conducted to investigate proper inclusion levels of tuna by-product meal without plant protein sources as a substitute of fishmeal for juvenile Korean rockfish diets.

Methods

Experimental diets

Proximate composition and amino acid composition of brown fishmeal and tuna by-product meal (Woojin Feed Ind. Co., Ltd., South Korea) used as protein sources in the experimental diets are shown in Table 1. Tuna by-product was prepared using tuna the heads, bones, fins, blood, and skin following the manufacture of canned Skipjack tuna (*Katsuwonus pelamis*) and Yellowfin tuna (*Thunnus albacares*). Tuna by-product meal was produced by routine method as follows. Raw materials were cooked by steaming (100–105 °C). They were compressed to separate oil. Subsequently, these materials were dried (100–105 °C) and pulverized. Five isonitrogenous (52% crude protein) and isocaloric (4.9 kcal/g) diets were prepared. Brown fishmeal (Chile) was included as control

(Con) diet. Fishmeal comprising 25, 50, 75, and 100% crude protein were substituted with the same percentage as crude protein in TBM25, TBM50, TBM75, and TBM100, respectively (Table 2). Squid liver oil and wheat flour were used as respective lipid and carbohydrate sources of diets. Experimental diets were prepared with a laboratory pellet machine after 35–40 ml of water was mixed with 100 g mixture of ingredients. All diets were dried for 48 h at room temperature and freezer-stored (–24 °C).

Experimental fish and rearing conditions

Korean rockfish (*Sebastes schlegeli*) obtained from a local fish farm (Tongyoung, Korea) were acclimated to laboratory conditions for 2 weeks before feeding trial. Experimental fish with an average initial body weight of 29.5 ± 0.6 g were randomly distributed into each of 15 cylindrical plastic tanks (400 L, 30 fish per tank) with a flow-through system. Three replicate groups of fish were hand-fed experimental diets to apparent satiation once daily (10:00, 6 days a week) (Lee et al. 2000) for 12 weeks. Mean water temperature during the rearing period was 16.6 ± 2.7 °C. All fish in each tank were weighed collectively at the beginning and the end of the feeding trial after 48 h fast.

Table 1 Nutrient contents (% DM) of dietary ingredients

	Brown fishmeal ^a	Tuna by-product meal ^b
Proximate composition		
Crude protein	77.2	64.6
Crude lipid	8.2	9.6
Ash	13.7	21.4
Indispensable amino acids		
Arginine	4.0	3.5
Cysteine	0.7	0.6
Histidine	2.9	1.7
Isoleucine	3.1	2.5
Leucine	5.1	4.1
Lysine	5.5	4.3
Methionine	2.2	1.8
Phenylalanine	3.0	2.2
Threonine	3.0	2.5
Valine	3.6	2.7
Dispensable amino acids		
Alanine	4.2	3.8
Aspartic acid	6.3	5.0
Glutamic acid	8.9	6.9
Glycine	4.1	4.2
Proline	2.8	3.4
Serine	2.8	2.4
Tyrosine	2.4	1.8

^aImported from Chile

^bSupplied by Woojin Feed Ind. Co., Ltd., Incheon Metropolitan City, South Korea

Sample collection and chemical analysis

At the end of the feeding trial, ten fish were taken from each experimental tank and stored in a freezer (–24 °C) for chemical analysis. Moisture contents of experimental diets and fish were measured after drying at 135 °C for 2 h. Crude protein content ($N \times 6.25$) was analyzed using an Auto Kjeldahl System (Gerhardt VAP50SC/KBL20, Germany). Crude lipid level was measured after extraction with ether employing a crude lipid extractor (Velp SER148, Italy). Ash content was determined following burning at 600 °C for 4 h using a muffle furnace. Gross energy of the experimental diet was analyzed using a calorimeter (PARR 6400, USA). Amino acid contents of experimental diets and fish were analyzed using an amino acid automatic analyzer (Biochrom 30+, England). Lipid for fatty acid analyses was extracted by a mixture of chloroform and methanol (2:1, v/v) according to the method of Folch et al. (1957). Fatty acid methyl esters were prepared by transesterification with 14% BF₃-MeOH (Sigma, St. Louis, MO, USA) and analyzed using a gas chromatograph (HP-6890 II; Hewlett-Packard, USA) equipped with a flame ionization detector and a HP-INNOWax capillary column (30 m × 0.32 mm i.d., film thickness 0.5 μm, Hewlett-Packard, USA). Injector and detector temperatures were set at 270 and 270 °C, respectively. The column temperature was programmed from 170 to 225 °C at a rate of 1 °C/min. Helium was used as carrier gas. Fatty acids were identified by comparison

Table 2 Ingredients and proximate composition of experimental diets

	Diets				
	Con	TBM25	TBM50	TBM75	TBM100
Ingredients (%)					
Brown fishmeal ^a	64.8	48.6	32.4	16.2	
Tuna by-product meal		19.3	38.7	58.1	77.5
Squid liver oil	4.6	4.1	3.6	3	2.5
α -Cellulose	10.6	8	5.3	2.7	
Wheat flour	18	18	18	18	18
Vitamin premix ^b	1	1	1	1	1
Mineral premix ^c	1	1	1	1	1
Proximate composition (% DM)					
Crude protein	52.7	52.6	52.6	52.6	52.6
Crude lipid	9.9	10.1	10.5	10.3	10.6
Ash	10.3	11.7	13.9	15.4	17.1
Gross energy (cal/g diet)	4949	4918	4852	4876	4830
Feed price (won/kg feed, DM) ^d	1903	1789	1674	1558	1443

^aProduced from Chile

^bThe vitamin premix contained the following ingredients diluted in cellulose (g/kg premix): L-ascorbic acid, 121.2; myo-inositol, 181.8; DL- α -tocopheryl acetate, 18.9; niacin, 36.4; p-aminobenzoic acid, 18.2; Ca-D-pantothenate, 12.7; riboflavin, 9.1; thiamin hydrochloride, 2.7; pyridoxine hydrochloride, 1.8; menadione, 1.8; retinyl acetate, 0.73; folic acid, 0.68; D-biotin, .27; cholecalciferol, 0.003

^cThe mineral premix contained the following ingredients diluted in dextrin (g/kg premix): NaCl, 30.3; MgSO₄·7H₂O, 95.6; NaH₂PO₄·2H₂O, 60.8; KH₂PO₄, 167.3;

CaH₄(PO₄)₂·H₂O, 94.7; Ferric citrate, 20.7; ZnSO₄·7H₂O, 15.3; Ca-lactate, 212.8; CuCl, 0.14; AlCl₃·6H₂O, 0.105; KI, 0.105; Na₂Se₂O₃, 0.01; MnSO₄·H₂O, 1.4; CoCl₂·6H₂O, 0.7

^dPrice in Korean won; one US\$ = 1060 won, based on 2018 exchange prices. The same labor and processing costs are included

with known standards. Amino acids and fatty acid compositions of experimental diets are shown Tables 3 and 4, respectively.

Statistical analyses

Statistical analyses were performed using one-way analysis of variance (ANOVA) followed by Duncan's multiple range test (Duncan 1955). SPSS version 11.5 (SPSS, Chicago, IL, USA) was employed for all statistical analyses. Statistical significance was considered at $p < 0.05$.

Results

Crude protein and essential amino acid contents of tuna by-product meal used as substitute of fishmeal in diets were slightly lower than those of brown fishmeal (Table 2). Growth performance and cost-benefit analyses of juvenile Korean rockfish fed experimental diets for 12 weeks are shown in Table 5. Survival rates of all experimental groups were 93–99%, without showing significant differences among groups. Weight gain and specific growth rate of fish fed Con and TBM25 diets were not significantly different from those of fish fed TBM50 or TBM75 diet. However, they were significantly ($p < 0.05$) higher than those of fish fed TBM100 diet. Feed efficiency and protein efficiency of fish fed Con diet were significantly ($p < 0.05$) higher than those of fish fed TBM100 diet. However, they were not significantly

different from those of fish fed TBM25, TBM50, or TBM75 diet. Daily feed intake was significantly ($p < 0.05$) influenced by experimental diets. TBM25, TBM50, TBM75, and TBM100 diets had significantly ($p < 0.05$) lower incidence cost but higher profit index than the Con diet. TBM50, TBM75, and TBM100 diets were the best economically, followed by TBM25 and Con diets.

Proximate compositions of the whole body of juvenile Korean rockfish fed experiment diets are shown in Table 6. Moisture, crude protein, or ash contents were not significantly different among all experimental groups. However, crude lipid content was significantly ($p < 0.05$) influenced by experimental diets. Amino acid compositions of the whole body of fish at the end of feeding trial were not significantly different among experimental diet groups (Table 7).

Discussion

In this study, survival rates of fish in all experimental groups were over 93%. There were no significant differences in growth or feed efficiency of fish fed Con, TBM25, TBM50, or TBM75 diet. This suggests that tuna by-product meal can replace 75% fishmeal protein without reducing growth or feed utilization in juvenile Korean rockfish (29–53 g). Since tuna by-product meal is less expensive than brown fishmeal, its use as a fishmeal substitute in practical feed is expected to lower feed costs without decreasing growth of juvenile Korean

Table 3 Amino acids compositions (% DM) of experimental diets

	Diets				
	Con	TBM25	TBM50	TBM75	TBM100
Indispensable amino acids					
Arginine	2.9	2.7	2.6	2.5	2.4
Cysteine	0.4	0.4	0.4	0.4	0.4
Histidine	2.2	1.9	1.7	1.7	1.3
Isoleucine	2.3	2.1	2.1	1.9	1.9
Leucine	3.7	3.4	3.4	3.2	3.1
Lysine	4.0	3.7	3.6	3.4	3.1
Methionine	1.5	1.3	1.4	1.3	1.2
Phenylalanine	2.2	2.0	2.0	1.8	1.8
Threonine	2.2	2.1	2.0	1.9	1.8
Valine	2.6	2.5	2.5	2.2	2.1
Dispensable amino acids					
Alanine	3.1	3.0	3.0	2.9	2.9
Aspartic acid	4.6	4.4	4.2	3.9	3.8
Glutamic acid	7.1	6.5	6.3	6.1	5.6
Glycine	3.1	3.0	3.1	3.2	3.2
Proline	2.2	2.2	2.2	2.3	2.4
Serine	2.0	2.0	1.9	1.8	1.7
Tyrosine	1.2	1.3	1.2	1.3	1.3

rockfish. In a previous study (Jeon et al. 2014), fishmeal could be replaced by tuna by-product meal prepared by fermenting a mixture of tuna fishmeal and soybean meal up to 40% without diminishing the growth of juvenile Korean rockfish (3–12 g), which is lower than the 75% replacement of fishmeal in this study. In previous studies on flounder, fishmeal could be replaced with tuna by-product meal prepared by fermenting a mixture of tuna fishmeal and soybean meal up to 30% without decreasing the growth of juvenile flounder (Kim et al. 2014). However, Uyan et al. (2006) have reported that tuna muscle by-product powder could replace 50% fishmeal without affecting growth performance of juvenile flounder. These differences in dietary substitution level of fishmeal with tuna by-product meal might be due to rearing conditions, fish sizes, inclusion of plant protein source such as soybean meal, nutrient contents such as essential amino acids, and digestibility of tuna by-product meal in diets. Lim et al. (2004) have reported that juvenile Korean rockfish (2.5 g initial weight) fed diets with 20% fishmeal replaced with soybean meal show reduced growth and feed efficiency compared to those fed with fishmeal-based control diet. Similar results of growth and feed efficiency were also observed in Korean rockfish with initial weight of 21.5 g fed diet having 20% fishmeal replaced with soybean meal and fishmeal-based

control diet. A prior study on Korean rockfish (Lee 2002) has reported that apparent digestibility coefficients for dry matter, crude protein, and energy of soybean meal in juveniles (30 g) are lower than those in growers (300 g) while both juvenile and grower Korean rockfish fed with fishmeal show higher apparent digestibility coefficients for dry matter, crude protein, and energy compared to those fed with soybean meal. Therefore, the lower nutrient digestibility of soybean meal contained in tuna by-product meal reported in the study of Jeon et al. (2014) might have reflected the difference in dietary substitution level between fishmeal and tuna by-product meal for juvenile Korean rockfish. Yan et al. (2007) have reported that dietary methionine requirement for maximum growth of juvenile rockfish is 1.37% in the presence of 0.12% cysteine. Methionine content in diets used in the present study ranged from 1.2–1.5%, which was higher than dietary methionine level of 0.76–1.0% in the study of Jeon et al. (2014). These differences in dietary methionine levels might have affected the growth of rockfish.

In the present study, juvenile Korean rockfish fed TBM100 diet (i.e., 100% replacement of fishmeal with tuna by-product meal) showed reduced growth and feed efficiency compared to those fed Con diet that contained only fishmeal as protein source. Contents of major

Table 4 Fatty acids compositions of experimental diets

	Diets				
	Con	TBM25	TBM50	TBM75	TBM100
Fatty acids (% of total fatty acids)					
C14:0	3.5	3.4	3.5	3.5	3.8
C16:0	18.4	19.5	20.3	21.7	25.1
C16:1n	4.0	4.2	4.5	4.8	6.1
C18:0	6.9	7.1	7.1	7.2	7.3
C18:1n-9	20.7	20.6	21.2	20.9	20.6
C18:2n-6	19.0	17.5	16.8	15.7	12.2
C18:3n-3	4.9	4.5	4.4	4.1	3.1
C20:0	0.7	0.7	0.7	0.7	0.8
C20:1n-9	1.0	1.2	2.0	2.2	2.3
C20:4n-6	1.2	1.2	1.2	1.2	1.5
C20:5n-3	5.0	4.9	4.5	4.4	4.3
C22:0	0.8	1.0	1.2	1.3	1.3
C22:5n-3	1.8	1.6	1.3	1.1	1.0
C22:6n-3	12.3	12.5	11.4	11.2	10.7
Fatty acids (% in diet, DM) ^a					
EPA	0.44	0.44	0.42	0.40	0.40
DHA	1.08	1.12	1.07	1.03	1.01
n-3HUFA	1.68	1.71	1.61	1.53	1.51

EPA eicosapentaenoic acid, DHA docosahexaenoic acid

^aFatty acids (% in diet), calculated (dietary total lipid × 0.892) (Yoshimatsu et al. 1997)**Table 5** Growth performance and cost-benefit analyses of juvenile Korean rockfish fed diets containing various levels of tuna by-product meal for 12 weeks

	Diets				
	Con	TBM25	TBM50	TBM75	TBM100
Initial mean weight (g/fish)	29.5 ± 0.3 ^{ns}	29.3 ± 0.5	29.2 ± 0.4	29.6 ± 0.4	29.5 ± 0.2
Survival (%)	98 ± 1.1 ^{ns}	93 ± 3.3	99 ± 1.1	98 ± 1.1	96 ± 4.4
Mean weight gain (g/fish)	23.5 ± 0.8 ^b	23.5 ± 0.5 ^b	21.3 ± 0.6 ^{ab}	22.2 ± 0.4 ^{ab}	19.7 ± 1.3 ^a
Specific growth rate (%/day) ^a	0.69 ± 0.02 ^b	0.69 ± 0.01 ^b	0.65 ± 0.01 ^{ab}	0.66 ± 0.01 ^{ab}	0.60 ± 0.03 ^a
Feed efficiency (%) ^b	61 ± 1.4 ^b	61 ± 1.1 ^b	63 ± 1.1 ^b	59 ± 1.6 ^b	51 ± 2.0 ^a
Protein efficiency ratio ^c	1.18 ± 0.03 ^b	1.20 ± 0.02 ^b	1.24 ± 0.02 ^b	1.17 ± 0.03 ^b	1.02 ± 0.04 ^a
Daily feed intake ^d	1.08 ± 0.01 ^{ab}	1.04 ± 0.02 ^{ab}	.99 ± 0.03 ^a	1.07 ± 0.02 ^{ab}	1.11 ± 0.04 ^b
Incidence cost ^e	3279 ± 76.7 ^c	2965 ± 56.1 ^b	2722 ± 48.5 ^{ab}	2625 ± 73.1 ^a	2819 ± 107.2 ^{ab}
Profit index ^f	3.72 ± 0.06 ^a	4.33 ± 0.10 ^b	4.86 ± 0.15 ^{bc}	4.86 ± 0.09 ^{bc}	5.25 ± 0.32 ^c

Values (mean ± SE of three replications) in each row that do not share a common superscript letter are significantly different ($P < 0.05$)^a $[\ln(\text{final body weight}) - \ln(\text{initial body weight})] \times 100/\text{day}$ ^bFish wet weight gain × 100/feed intake (dry matter)^cFish wet weight gain/protein intake^dFeed intake (or protein) × 100/((initial fish wt. + final fish wt. + dead fish wt.) × days fed/2)^eCost of kilogram feed consumed/kg fish produced^fValue of fish crop (8300 won/kg)/cost of feed consumed^{ns}Not significant ($P > 0.05$)

Table 6 Proximate composition (%) of the whole body in juvenile Korean rockfish fed diets containing various levels of tuna by-product meal for 12 weeks

	Diets				
	Con	TBM25	TBM50	TBM75	TBM100
Moisture	67.2 ± 0.35 ^{ns}	67.0 ± 0.39	67.4 ± 0.24	67.5 ± 0.15	67.3 ± 0.41
Crude protein	16.8 ± 0.31 ^{ns}	17.2 ± 0.22	17.0 ± 0.15	17.1 ± 0.19	17.2 ± 0.23
Crude lipid	9.7 ± 0.35 ^b	8.9 ± 0.26 ^{ab}	8.5 ± 0.33 ^a	9.1 ± 0.23 ^{ab}	8.7 ± 0.44 ^{ab}
Ash	4.9 ± 0.42 ^{ns}	4.7 ± 0.29	4.8 ± 0.09	4.6 ± 0.1	4.7 ± 0.29

Values (mean ± SE of three replications) in each row that do not share a common superscript letter are significantly different ($P < 0.05$)

^{ns}Not significant ($P > 0.05$)

nutrients such as essential amino acids were lower in tuna by-product meal than those in brown fishmeal diets. Growth and feed efficiency of fish can differ according to the quality of fishmeal in diets (Caballero et al. 1999). Fishmeal quality depends on nutrient contents and digestibility, freshness of raw materials, and processing conditions used for fishmeal manufacturing (Aksnes and Mundheim 1997). In the study of Aksnes and Mundheim (1997), Atlantic halibut showed slower growth when the freshness of materials for fishmeal in diets was decreased.

Most marine fish require n-3 highly unsaturated fatty acids (HUFA) such as eicosapentaenoic acid and

docosahexaenoic acid for normal growth and development (Furuita et al. 2002; Bell and Dick 2004). In a previous study by Lee (2001), n-3 HUFA requirement for optimum growth of juvenile Korean rockfish was reported to be at 0.9%. As n-3 HUFA levels in experimental diets ranged from 1.51 to 1.71% in the present study, these could be used as sources of essential fatty acids in all diets to satisfy n-3 HUFA requirements of Korean rockfish.

Cost-benefit analyses including incidence cost and profit benefit of diets indicated that TBM was more economical than imported fishmeal because of this local availability at low prices.

Table 7 Amino acid composition (%) of the whole body in juvenile Korean rockfish fed diets containing various levels of tuna by-product meal for 12 weeks

	Diets				
	Con	TBM25	TBM50	TBM75	TBM100
Indispensable amino acids					
Arginine	1.07 ± 0.03 ^{ns}	0.91 ± 0.01	0.96 ± 0.03	0.97 ± 0.09	0.96 ± 0.08
Cysteine	0.18 ± 0.00 ^{ns}	0.17 ± 0.02	0.16 ± 0.00	0.18 ± 0.02	0.14 ± 0.01
Histidine	0.39 ± 0.01 ^{ns}	0.34 ± 0.00	0.34 ± 0.01	0.34 ± 0.03	0.36 ± 0.03
Isoleucine	0.67 ± 0.01 ^{ns}	0.57 ± 0.04	0.65 ± 0.02	0.66 ± 0.06	0.75 ± 0.14
Leucine	1.15 ± 0.00 ^{ns}	0.98 ± 0.04	1.08 ± 0.03	1.10 ± 0.09	1.01 ± 0.04
Lysine	1.27 ± 0.01 ^{ns}	1.11 ± 0.03	1.17 ± 0.03	1.21 ± 0.10	1.17 ± 0.09
Methionine	0.50 ± 0.02 ^{ns}	0.48 ± 0.04	0.55 ± 0.00	0.50 ± 0.05	0.50 ± 0.03
Phenylalanine	0.74 ± 0.05 ^{ns}	0.63 ± 0.04	0.69 ± 0.02	0.64 ± 0.07	0.64 ± 0.05
Threonine	0.74 ± 0.01 ^{ns}	0.62 ± 0.01	0.68 ± 0.02	0.66 ± 0.06	0.66 ± 0.06
Valine	0.76 ± 0.02 ^{ns}	0.63 ± 0.04	0.73 ± 0.02	0.73 ± 0.07	0.66 ± 0.01
Dispensable amino acids					
Alanine	1.05 ± 0.09 ^{ns}	0.92 ± 0.03	1.01 ± 0.04	1.01 ± 0.08	0.81 ± 0.12
Aspartate	1.65 ± 0.01 ^{ns}	1.38 ± 0.03	1.51 ± 0.04	1.51 ± 0.14	1.46 ± 0.12
Glutamate	2.20 ± 0.02 ^{ns}	1.89 ± 0.03	2.01 ± 0.05	2.02 ± 0.19	2.05 ± 0.17
Glycine	1.47 ± 0.08 ^{ns}	1.18 ± 0.07	1.26 ± 0.08	1.24 ± 0.09	1.28 ± 0.10
Proline	0.87 ± 0.04 ^{ns}	0.78 ± 0.05	0.81 ± 0.05	0.76 ± 0.04	0.84 ± 0.09
Serine	0.79 ± 0.02 ^{ns}	0.67 ± 0.02	0.72 ± 0.03	0.70 ± 0.06	0.72 ± 0.06
Tyrosine	0.57 ± 0.03 ^{ns}	0.50 ± 0.03	0.55 ± 0.02	0.54 ± 0.06	0.52 ± 0.05

Values are the mean ± SE of three replications

^{ns}Not significant ($P > 0.05$)

Moisture and crude protein contents of the whole body were not significantly affected by experimental diets in this study. In contrast, Jeon et al. (2014) have reported that increased tuna by-product meal substitution in diets tends to elevate moisture content but lower crude protein content in fish.

Although differences in essential amino acids such as histidine, leucine, and lysine in diets were observed, amino acid contents of the whole body were not significantly different among experimental groups in this study. In a prior study involving Korean rockfish (Jeon et al. 2014), contents of essential amino acids in juvenile rockfish were not affected by dietary tuna by-product meal levels. Similarly, Yamamoto et al. (2000) have reported that whole body amino acid compositions in rainbow trout fed with various dietary compositions do not show marked differences. These observations are expected because body proteins are synthesized based on genetic information from DNA. Thus, amino acid compositions of specific body proteins are the same irrespective of dietary treatments.

Conclusions

Tuna by-product meal used in this study could replace fishmeal protein up to 75% in the diet without reducing growth or feed utilization in juvenile Korean rockfish (29–53 g). By considering feed cost, the TBM 75 diet is recommendable for Korean rockfish farming.

Abbreviations

DHA: Docosahexaenoic acid; EPA: Eicosapentaenoic acid; HUFA: Highly unsaturated fatty acids; KITA: Korea International Trade Association; TBM: Tuna by-product meal

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Availability of data and materials

All datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

K-DK participated in research design, feeding trial, sample collection, data analysis, statistical analysis, and writing the paper. JWJ participated in chemical analysis, data analysis, and writing the paper. K-WK participated in research design, feeding trial, and sample collection. B-JL participated in research design, feeding trial, and sample collection. SWH participated in the data analysis and writing the paper. H-SH participated in research design, data analysis, and writing the paper. All authors read and approved the final manuscript.

Ethics approval

All experimental protocols followed guidelines of the Institutional Animal Care and Use provided by Committee of the National Institute of Fisheries and Science.

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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References

- Aksnes A, Mundheim H. The impact of raw material freshness and processing temperature for fish meal on growth, feed efficiency and chemical composition of Atlantic halibut (*Hippoglossus hippoglossus*). *Aquaculture*. 1997;149:87–106.
- Bell MV, Dick JR. Changes in capacity to synthesise 22:6n-3 during early development in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*. 2004;235:393–409.
- Caballero MJ, López-Calero G, Socorro J, Roo FJ, Izquierdo MS, Fernández AJ. Combined effect of lipid level and fish meal quality on liver histology of gilthead seabream (*Sparus aurata*). *Aquaculture*. 1999;179:277–90.
- Duncan DB. Multiple-range and multiple F tests. *Biometrics*. 1955;11:1–42.
- Folch J, Lees M, Sloane-Stanley GH. A simple method for the isolation and purification of total lipids from animal tissues. *J Biol Chem*. 1957;226:496–509.
- Furuta H, Tanaka H, Yamamoto T, Suzuki N, Takeuchi T. Effects of high levels of n-3 HUFA in broodstock diet on egg quality and egg fatty acid composition of Japanese flounder, *Paralichthys olivaceus*. *Aquaculture*. 2002;210:323–33.
- Jeon GH, Kim HS, Hyung SH, Cho SH. The effect of the dietary substitution of fishmeal with tuna by-product meal on growth, body composition, plasma chemistry and amino acid profiles of juvenile Korean rockfish (*Sebastes schlegelii*). *Aquac Nutr*. 2014;20:753–61.
- Kim HS, Jung WG, Myung SH, Cho SH, Kim DS. Substitution effects of fishmeal with tuna byproduct meal in the diet on growth, body composition, plasma chemistry and amino acid profiles of juvenile olive flounder (*Paralichthys olivaceus*). *Aquaculture*. 2014;431:92–8.
- KITA. Korea International Trade Association. Korea Trade Statistics; 2016. Retrieved from <http://global.kita.net>. Cited 21 Feb 2017
- Lee SM. Review of the lipid and essential fatty acid requirements of rockfish (*Sebastes schlegelii*). *Aquac Res*. 2001;32:8–17.
- Lee SM. Apparent digestibility coefficients of various feed ingredients for juvenile and grower rockfish (*Sebastes schlegelii*). *Aquaculture*. 2002;207:79–95.
- Lee SM, Hwang UG, Choi SH. Effects of feeding frequency and dietary moisture content on growth, body composition and gastric evacuation of juvenile Korean rockfish (*Sebastes schlegelii*). *Aquaculture*. 2000;187:399–409.
- Lee SM, Kim DJ, Choi SH. Effects of dietary protein and lipid level on growth and body composition of juvenile ayu (*Plecoglossus altivelis*) reared in seawater. *Aquac Nutr*. 2002;8:53–8.
- Lim SR, Choi SM, Wang XJ, Kim KW, Shin IS, Min TS, Bai SC. Effects of dehulled soybean meal as a fish meal replacer in diets for fingerling and growing Korean rockfish *Sebastes schlegelii*. *Aquaculture*. 2004;231:457–68.
- Statistics Korea. Fishery production survey. 2016. Retrieved from <http://kostat.go.kr>
- Uyan O, Koshio S, Teshima SI, Ishikawa M, Thu M, Alam MS, Michael FR. Growth and phosphorus loading by partially replacing fishmeal with tuna muscle by-product powder in the diet of juvenile Japanese flounder, *Paralichthys olivaceus*. *Aquaculture*. 2006;257:437–45.
- Vergara JM, Lopez-Calero G, Robaina L, Caballero MJ, Montero D, Izquierdo MS, Aksnes A. Growth, feed utilization and body lipid content of gilthead seabream (*Sparus aurata*) fed increasing lipid levels and fish meals of different quality. *Aquaculture*. 1999;179:35–4.

- Yamamoto T, Unuma T, Akiyama T. The influence of dietary protein and fat levels on tissue free amino acid levels of fingerling rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*. 2000;182:353–72.
- Yan Q, Xie S, Zhu X, Lei W, Yang Y. Dietary methionine requirement for juvenile rockfish *Sebastes schlegelii*. *Aquac Nutr*. 2007;13:163–9.
- Yoshimatsu T, Imoto H, Hayash M, Toda K, Yoshimara K. Preliminary results in improve essential fatty acids enrichment of rotifer cultured in high density. *Hydrobiologia*. 1997;358:153–7. https://doi.org/10.1007/978-94-017-2097-7_23

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