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Effects of Plant Ingredients on Physicochemical Properties of Extruded Fish Feed

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Abstract

The aim of this study was to determine the effects of different soy protein concentrate (0, 15, 30, and 45%), defatted soy flour (0, 10, 20, and 30%), and wheat flour (10, 20, and 30%) contents replacing fish meal on physiochemical properties of extruded aquatic feed by using a twin screw extruder. The moisture content, barrel temperature, die diameter, and screw speed were adjusted to 45%, 137°C, 4 mm, and 250 rpm, respectively. With the higher amount of soy protein concentrate replacing fish meal, the expansion ratio, swelling ratio, and water stability increased significantly while specific length and water holding capacity decreased significantly. With the increasing defatted soy flour content, expansion ratio increased significantly, but specific length, water holding capacity and water stability decreased significantly. With increase in the wheat flour content, the specific length significantly decreased while the water stability significantly increased. In conclusion, aquatic feed quality was optimized in this study and could be used in the future.

Key words: physicochemical properties, extrudates, plant ingredients

Introduction

Extrusion cooking has been widely used in the food industry as a high temperature short time (HTST) process to produce commercially shelf stable products, because of low cost, high productivity, energy efficiency and versatility (Angela, 2007). Extrusion offers continuous processing and could also maintain significant nutrient levels of ingredients (Guy, 2001). Physicochemical changes take place during the process which includes denaturation of protein, gelatinization of starch and Maillard reaction.

Aquaculture is one of the fastest growing food production activities in the world. It plays a significant role in many countries by providing a higher income, better nutrition, and better employment opportunities (Umar et al., 2013). Yoshitomi (2004) suggested that fish feed performance is judged mainly by three important factors that an ideal fish feed should have: (1) a reasonable nutritional quality that also suggests high digestibility and absorbability; (2) a suitable texture; (3) the palatability. The physical properties of pellets should be high in order to withstand handling, transportation and pneumatic conveying, without generation of excessive amount of dust and fine particles (Khater et al., 2014), so the physical properties of extruded fish feed has become important. The largest cost component in aquaculture production is feed; protein is often the most expensive nutritional factor. Therefore, using low-price alternate sources of protein, which could provide better fish growth, is beneficial for feed manufacturers and aquaculture producers alike.

Aquatic soybean protein concentrate (SPC) has proven to be an excellent plant protein source in fish and shrimp feed. Although it has low level of antigen, ash and phosphorus unlike fish meal as high levels of bio-amine, but also has excellent granulation. Appropriate amount can increase the survival rate of breed varieties; maintain normal growth, while improving the efficiency of feed use (Singh et al., 2007). Defatted soy flour (DSF) is generally made from defatted soybean meal. Fat content is generally less than 1.0%, protein content is higher than 50%. One of defatted soy flour after degreasing and high temperature can be directly used as animal feed. Wheat flour contains a lot of carbohydrates. Starch is best characterized in terms of loss of crystalline and gelatinization during extrusion. Starch plays a vital role in the

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production of floating versus sinking feeds because it acts as a binder and impacts product expansion. The minimum starch content needed for floating and sinking feeds are generally 18-22 and 9-11%, respectively. The main effect of extrusion on starch is to promote the intermolecular hydrogen bond cleavage and gelatinization. The effective gelatinization of starch makes the extrusion treatment not only improve the nutrition of the material, but also facilitate the material molding, thereby improving the physical quality (Ye et al., 2018).

In addition, many researchers reported that plant ingredients could improve the quality of fish feed (Venou et al., 2006; Traynham et al., 2007; Kraugerud & Svihus, 2011; Morken et al., 2011; Sørensen, 2012; Umar et al., 2013). However, soy protein concentrate, defatted soy flour, and wheat flour were seldom found. Therefore, this study aimed to investigate the effects of different plant ingredient contents on physicochemical properties of fish feed.

MATERIALS AND METHODS

Materials

Fish meal was provided by Korea Aquatic Life Institute Co. Ltd. (Busan, Korea). Its composition was: moisture 8% and protein 69%. Defatted soy flour (moisture 7% and protein 50%), third grade wheat flour (moisture 12%, protein 9.2% and crud ash 0.98%), and soy protein concentrate (moisture 5% and protein 95%) were bought from Gaemifood Co. (Eumseong, Korea), Sinsung O & F Co. (Hoengseong, Korea) and Es Food material Co. (Gunpo, Korea), respectively.

Experimental formula and extrusion process

Table 1. Formula of different plant ingredient substitute content

	Fish meal	SPC	DSF	Wheat flour
Contents (%)	65	0	10	17
	50	15	10	17
	35	30	10	17
	20	45	10	17
	65	0	0	17
	55	0	10	17
	45	0	20	17
	35	0	30	17
	55	0	10	10
	45	0	10	20
	35	0	10	30

SPC, soy protein concentrate; DSF, defatted soy flour

Table 1 shows the experimental formula and the materials of the extruded pellets. Extrusion was performed in a twin-screw extruder (THK 31T, Incheon Machinery Co., Incheon, Korea). The extrusion conditions were moisture content of 45%, barrel temperature of 137°C, die diameter of 4 mm, and screw speed of 250 rpm. Extruded fish feed was dried at 50°C for 8 h and ground into powder to pass through a 50-70 mesh sieve. The dried fish feed was chosen randomly to analyze the physical properties and the powder for chemical analysis.

Expansion ratio and specific length

Ten samples were randomly selected, and their diameter, length and weight were measured (Khater et al., 2014). Expansion ratio was calculated as the diameter of extrudates divided by die diameter while specific length was evaluated as the length of extrudates divided by weight of extrudates.

Water holding capacity and swelling ratio

Ten pellets of each sample were soaked in distilled water at room temperature for 1 h (Yoshitomi, 2004). The soaked pellets were filtered through a 20 mesh screen and were left to sit for 5 min, and then weighed. The diameter of soaked samples was also determined with digital Vernier caliper (CD-15CPX, Mitutoyo Corp., Kawasaki, Japan). The water holding capacity data was reported as grams of water retained for each gram of product and the swelling ratio was calculated as the diameter of pellets after soaking divided by the diameter of pellets before soaking.

Water stability

Samples (10 g, wet basis) and 500 mL of tap water were placed into 1,000 mL of soluble extraction bath (TW-SM, Wooju Scientific Co., Pohang, Korea). Each sample was stirred in the soluble extraction bath at room temperature and was shaken at 100 rpm for 1, 2 and 3 h. The sample was filtered by 20 mesh screens, and dried at 105°C until equilibrium was reached. The water stability was calculated by using the following formula (1).

$$\text{Water stability (\%)} = (\text{Final weight}/\text{Initial weight}) \times 100 \quad (1)$$

Protein digestibility

The protein digestibility (PD) was determined by slightly modified method of Thin et al. (2016). For the undigested protein content, 0.2 g powder was mixed with 35 mL pepsin solution in micro tube (1.5 g pepsin/1,000 mL of 0.084 N

HCl). The mixture was digested at 37°C for 2 h at 150 rpm in a shaker (SI-300R, Jeio Tech Co., Ltd., Daejeon, Korea). Then, 2 mL of 2 M NaOH was added to stop reaction. The reacted solutions were centrifuged at 3,000 rpm for 15 min. The residues were dried at 50°C for 12 h. The sediments were used to analyze the protein content with Ninhydrin method by using albumin protein as a standard (Starcher, 2001). For the determination of total protein content of the sample, 10 mg was hydrated with 6 N HCl solution of 500 μL at 100°C for 24 h. The hydrated sample was redissolved in 1.4 mL distilled water and centrifuged at 3,000 rpm for 30 min. After centrifugation, the supernatant was collected for analyzing total protein content. The PD was expressed by following Eq. (2):

$$PD\ (\%) = [(\text{Total protein} - \text{Undigested protein})/\text{Total protein}] \times 100 \quad (2)$$

Statistical analysis

Data were analyzed by using Excel program and SPSS program (Version 20.0, SPSS Inc, Chicago, IL, USA).

Results and Discussion

Expansion ratio and specific length

The results of expansion ratio are shown in Table 2. Higher amount of soy protein concentrate and defatted soy flour content led to greater expansion (0.89 to 1.19). This may be attributed by the more protein content in the ingredient mix which results in production of porous extrudates due to protein denaturation and plastic behavior of the melted dough inside the extrusion barrel (Chevanan et al., 2007; Fallahi et al., 2012). Ingredients with high natural protein will plasticize under heat, which will cause good quality pellets. With increase in wheat flour content, the significant difference was not observed in expansion ratio. It is indicated that small amount (10-30%) of starch could not work for producing expanded pellets. Mercier & Feiliet (1975) said that the ratio of amylose/amylopectin is the main effect on expansion ratio. Studies have shown that amylose content in a certain range can increase the expansion ratio, but more than the content of expansion ratio will decline (Chinnaswamy & Hanna, 1988).

As shown in Table 3, the specific length was significantly (r = -0.801 at p<0.01) and negatively correlated with expansion ratio. With the increase in soy protein concentrate and wheat flour content, the specific length significantly decreased (Table 2) which indicated that the sample occurred diameter expansion. With increase in defatted soy flour content, the specific length decreased from 16.95 to 9.11 cm/g, except for 30% defatted soy flour, its value was 11.00 cm/g. At 30% defatted soy flour content, the specific length increased 17%, compared to 20% defatted soy flour substitution. It showed that aquatic feed expanded not only radical direction but also longitudinal direction.

Water holding capacity and swelling ratio

The water holding capacities of samples are shown in Table 2. As increasing the soy protein concentrate and defatted soy flour content, the water holding capacity significantly decreased. But there was no significant influence among 10, 20, and 30% defatted soy flour content. When fish meal was substituted with soy protein concentrate, water holding capacity showed significant (r = - 0.632 at p<0.05) negative correlation

Table 2. Physical properties of extruded fish feed

	Contents (%)	ER	SL (cm/g)	WHC (%)	SR	WS (%)
SPC	0	0.98±0.06[a]	12.28±0.23[a]	541.51±0.08[a]	1.40±0.11[ab]	82.26±0.26[d]
	15	1.07±0.03[b]	8.86±0.14[b]	502.37±0.18[b]	1.37±0.09[b]	86.53±0.34[b]
	30	1.18±0.04[c]	7.57±0.22[c]	451.22±0.12[c]	1.39±0.07[b]	85.36±0.41[c]
	45	1.19±0.05[c]	7.14±0.20[c]	448.44±0.05[c]	1.50±0.13[a]	87.45±0.44[a]
DSF	0	0.89±0.10[a]	16.95±0.85[a]	639.76±0.35[a]	1.37±0.17[a]	87.84±0.37[a]
	10	1.06±0.03[b]	9.11±0.46[c]	546.87±0.25[b]	1.36±0.09[a]	86.46±0.29[b]
	20	1.16±0.05[c]	9.39±0.26[c]	507.18±0.23[b]	1.39±0.08[a]	86.37±0.17[b]
	30	1.13±0.05[c]	11.00±0.35[b]	549.36±0.21[b]	1.35±0.11[a]	80.79±0.84[c]
WF	10	1.00±0.12[a]	14.01±0.46[a]	617.77±0.20[a]	1.36±0.21[a]	83.57±0.13[b]
	20	1.08±0.14[a]	11.23±0.57[b]	578.21±0.22[a]	1.43±0.19[a]	83.50±0.45[b]
	30	0.99±0.07[a]	11.62±0.61[b]	588.22±0.12[a]	1.50±0.13[a]	84.91±0.20[a]

SPC, soy protein concentrate; DSF, defatted soy flour; WF, wheat flour; ER, expansion ratio; SL, specific length; WHC, water holding capacity; SR, swelling ratio; WS, water stability
Values with different letters at the same material are significantly different (p<0.05).

Table 3. Correlation coefficients of physical properties of extruded fish feed by adding different plant ingredients

		ER	SL	WHC	SR	WS	PD
SPC	ER	1					
	SL	-0.801**	1				
	WHC	-0.632*	0.459	1			
	SR	-0.12	-0.144	0.254	1		
	WS	0.684*	-0.53	-0.705*	-0.296	1	
	PD	-0.21	0.03	-0.01	0.201	-0.294	1
DSF	ER	1					
	SL	-0.666**	1				
	WHC	-0.057	-0.009	1			
	SR	-0.044	0.037	-0.071	1		
	WS	-0.243	0.517	0.324	0.469	1	
	PD	-0.409	-0.123	0.47	-0.399	-0.069	1
WF	ER	1					
	SL	-0.357	1				
	WHC	0.688*	0.014	1			
	SR	-0.511**	0.096	0.665	1		
	WS	-0.537	-0.198	-0.407	-0.09	1	
	PD	-0.345	0.174	-0.201	0.05	-0.254	1

SPC, soy protein concentrate; DSF, defatted soy flour; WF, wheat flour; ER, expansion ratio; SL, specific length; WHC, water holding capacity; SR, swelling ratio; WS, water stability; PD, protein digestibility
*Significant at $p<0.05$; **Significant at $p<0.01$

with expansion ratio (Table 3). With increasing the wheat flour content, the water holding capacity had no significant difference (Table 2). It was noteworthy that the water holding capacity showed significant (r = 0.688 at $p<0.05$) positive correlation with expansion ratio (Table 3).

The values of swelling ratio were shown in Table 2. With increasing soy protein concentrate content, the swelling ratio increased. With increasing defatted soy flour content and wheat flour content, there were no significant ($p<0.05$) difference. The swelling ratio was significantly (r = -0.511 at $p<0.01$) and negatively correlated with expansion ratio (Table 3). These findings suggest that defatted soy flour and carbohydrate is not the most important binder in extruded feed (Zimonja & Svihus, 2009).

Water stability

The water stability is shown in Table 2. Higher amount of soy protein concentrate and wheat flour content resulted in significant increases of water stability. The best value (87.45%) was found at 45% soy protein concentrate content. The water stability has significant positive (r = 0.684 at $p<0.05$) correlation with expansion ratio, but a significant (r = -0.705 at $p<0.05$) negative correlation with water holding capacity with increasing in soy protein concentrate content. A significant ($p<0.05$) reduction of water stability was found as the defatted soy flour content increased (Table 2). Depending on the composition, when replacing fish meal content with defatted soy flour, the results in this study were in line with the report of Bandyopadhyay & Rout (2001).

Protein digestibility

Fishmeal and other processed fishery by-product protein sources are an excellent source of highly digestible protein, long chain omega-3 fatty acids (eicosapentaenoic acid (EPA) and docosaheaxenoic acid (DHA)) and essential vitamins and minerals. Protein nutritional value depends on quantity, digestibility and availability of essential amino acids. Digestibility is considered as the most important determinant of protein quality. Protein digestibility (PD) refers to the percentage of proteins that are absorbed in the digestive tract. A protein with high digestibility has potentially better nutritional value than that with low digestibility because it would provide more amino acids for absorption on proteolysis. The values of protein digestibility were shown in Fig. 1. It was indicated that, after extrusion, the values of protein digestibility were higher than before extrusion. According Singh et al. (2007), protein digestibility value of extrudates is higher than non-extruded products. The possible cause might be the denaturation of

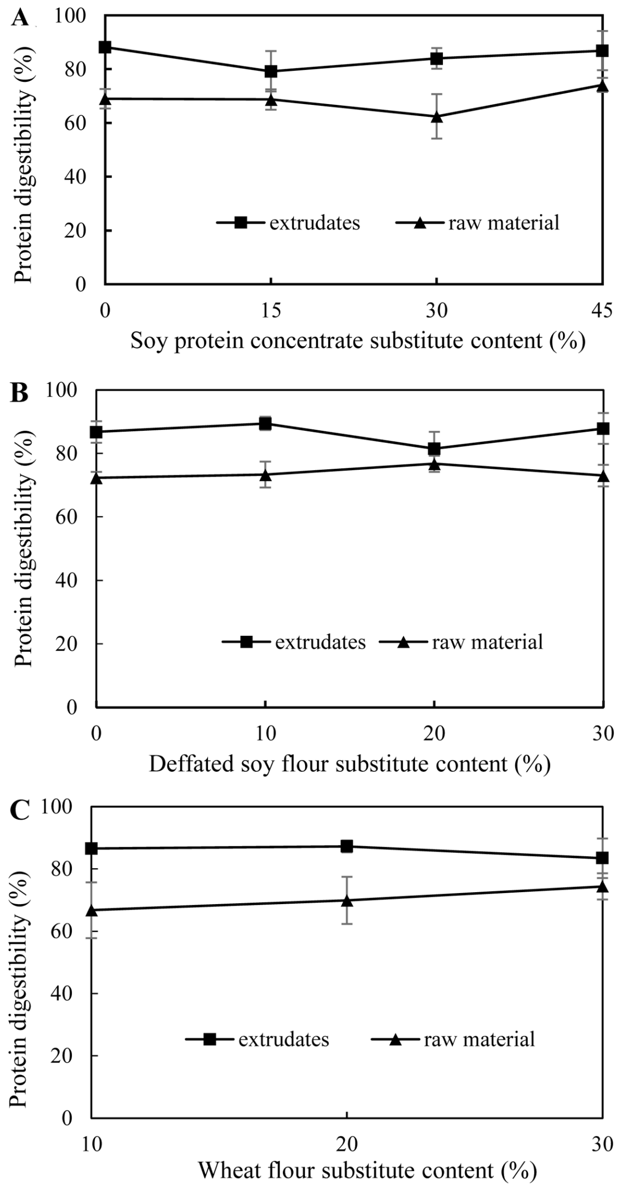

Fig. 1. The protein digestibility of extruded fish feed.

proteins and inactivation of antinutritional factors that impair digestion.

Conclusion

Using soy protein concentrate as fish meal replacer in aquatic feed led to an increase in expansion ratio, swelling ratio, and water stability; a decrease in specific length and water holding capacity. Replacing fish meal with defatted soy flour resulted in increased expansion ratio and decreased specific length, water holding capacity, and water stability. However, as wheat flour substituting fish meal, specific length decreased and water stability increased. To sum up, high-quality aquatic feed was achieved in this study and can be used in aquaculture industry.

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