ハマチ用ソフトドライペレット(SDP)のタンパク源としての脱脂大豆粕の利用

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Utilization of Soybean Meal as a Protein Source in a Newly Developed Soft-dry Pellet for Yellowtail

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The availability of defatted soybean meal (SBM) as a substitute for fish meal in a newly developed soft-dry pellet (SDP) was evaluated in juvenile (160 g on average) and adult (1,200 g on average) yellowtail by feeding SDP containing 0–30% SBM for 74 and 143 days, respectively.

Palatability and acceptability in both sizes of fish were not affected by the inclusion of SBM in SDP, while growth and feed gain ratio were slightly reduced at higher SBM levels, probably due to the nitrogenous and caloric imbalance of the diets. There were no marked differences in proximate composition and rheological properties of muscle together with hemochemical parameters in either juvenile or adult yellowtail fed on SDP containing 0–30% SBM. Digestibility of crude protein in the experimental SDP and SBM was about 85% regardless of dietary SBM levels, while that of crude starch was reduced by the elevation of dietary SBM levels.

The results of the present study have shown that SBM can be included in the SDP up to 30% as a substitute for fish meal, although elevation of a protein or energy level will be required to obtain feed performances comparable to a fish meal diet.

Rapid improvements in fish culture techniques have compounded the demand for fish feeds which depend inordinately on fish meal as the protein source. Over the next decade, shortfalls in the capture of meal-grade fish from the wild are expected.[1] This situation has already been experienced in the case of sardine, an important component of fish meal in Japan, the catch of which has dropped over a million t during the last couple of years.[1] To overcome this shortage, efforts are now being directed to finding alternative protein sources of good nutritional value as substitutes for the expensive fish meal component in practical diets.

Among various protein sources available for fish feeds, soybean meal has universal acceptance, both qualitatively and quantitatively. Soybean meal has a favorable amino acid profile as compared to other plant protein sources, is consistently available, is cost effective, and is reported to be palatable to most species of fish.[2]

The total production of yellowtail *Seriola quinqeradiata* in Japan was about 160,000 t in 1989, representing about 70% of the total production of cultured marine finfish.[1] Total consumption of formulated feed in terms of mash to prepare the so-called moist pellets was about 38,000 t, while besides this, 1.6–1.8 million t of sardine were directly utilized as feed for yellowtail in 1988.[3] However, on feeding moist pellets, alternative protein sources could not be included as a principal component. Very recently a completely new type of dry pellet, termed the "soft-dry pellet,"[4] has been developed for the yellowtail. This soft-dry pellet, produced by using a twin extruder, is highly palatable and acceptable to yellowtail and superior to moist pellets and raw fish in nutritional value. The use of the soft-dry pellet has also opened up the possibility of utilizing alternative protein sources as substitutes for fish meal in practical diets.

This study, therefore, evaluates the availability

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of soybean meal as a protein source in soft-dry pellets for the yellowtail.

Materials and Methods

Feeding Conditions

Feeding experiments were conducted with juvenile (Expt. I) and one-year-old (Expt. II) yellowtail in floating net cages located at an inlet near the Wakayama Prefectural Institute of Aquaculture.

Expt. I: Juvenile yellowtail weighing around 160 g were used for the feeding experiment. Initially these fish were collected as wild-caught fry of around 5.5 g on average on June 27th, and then were fed with a commercial soft-dry pellet (Sakamoto Fish Feed Co.) till September 4th (60 days feeding). They were then divided into four groups of 627 each, kept in the net cages (3×3×3 m) with a net cover, and fed the experimental diets containing different levels of soybean meal from September 5th to December 11th (74 days feeding). Fish were fed 6 days a week, twice a day (10:00 and 16:00), each time to about 70–80% of the satiation level (2.0–5.0% of body weight), which was determined during the preliminary feeding. Their average body weight was determined every month by weighing all the fish in the cages. During the first month of feeding many dark colored fish were observed in all the experimental groups. This abnormality was presumed to be caused by the destruction of vitamins or oxidation of lipids in diets over a relatively long term (about 5 months) storage of the experimental diets under natural conditions in a storehouse. However, supplementation of a commercial vitamin mixture to the diets by adsorbing the mixture dissolved in water effectively improved this condition. Therefore, the vitamin mixture was supplemented to the diets every third day for about one month. The abnormal fish were all deleted from each lot at the time of total body weight determination. Therefore, the number of fish in each lot varied from the second period of feeding. At the second determination of total body weight, the number of fish in each cage was again reduced to about 310 to accommodate the density. At the end of feeding three fish were taken from each lot for proximate analysis.

Expt. II: One-year-old yellowtail weighing 740–790 g, which had been fed raw fish and moist pellets for one year, were divided into three groups of about 220 each and kept in net cages (3×3×3 m). Two groups were fed a commercial soft-dry pellet (Sakamoto Fish Feed Co.) for one month up to 1,134 g and 1,157 g respectively, in order to accustom them to the experimetal soft-dry pellets with or without soybean meal. The third group was fed with raw sand lance for the same period up to 935 g on average for comparison with the test pellets. The number of fish was reduced to 133, 135, and 168 for the control, 30% SBM, and sand lance groups, respectively, in order to adjust the total fish weight per net cage. They were then fed the experimental diets (two types of dry pellets and sand lance) 6 days a week, once a day in the evening (1.0–2.5% of body weight). The feeding rate of the raw fish group was adjusted to 3–4 times the dry pellets. The feeding period was from June 14th to December 12th (143 days feeding). During the feeding experiment the average body weight was recorded every one and half months by weighing all the fish in the cages. At the end of feeding, three fish were taken from each lot for analysis of protein and lipid contents of muscle. The analytical procedures for proximate composition were those described previously.[5]

The initial recording of water temperature was 21°C; a midterm high of 28°C was followed by a drop to 18°C towards the final phase of feeding.

Experimental Diets

The composition of the experimental diets and their proximate values are shown in Table 1. A control diet with 56% fish meal as a main protein source and without soybean meal was formulated as being close to a practical soft-dry diet for yellowtail. In order to evaluate the availability of soybean meal as a protein source, the experimental diets for juveniles contained respectively 10, 20, and 30% soybean meal, replacing identical levels of fish meal in the control diet. In one-year-old yellowtail the nutritional value of a diet containing 30% soybean meal was compared with the control diet and raw sand lance. All the experimental dry diets were incorporated with 10% krill meal as a protein source in order to enhance pigmentation of the skin. The mineral and vitamin mixtures were prepared to satisfy the requirements of yellowtail.[6] The soybean meal purchased from Showa Sangyo Co. was ordinary defatted material containing 46% crude protein. The other ingredients used

Table 1. Composition of the experimental diets with or without soybean meal (SBM) for the juvenile (Expt. I) and adult yellowtail (Expt. II)

Ingredient (%)	Expt. I				Expt. II		
	SBM in diet				SBM in diet		
	0%	10%	20%	30%	0%	30%	
	Diet no.				Diet no.		
	1*1	2	3	4	1*1	2	3
Fish meal*2	56	46	36	26	55	25	Raw sand lance
Soybean meal*3	0	10	20	30	0	30	
Krill meal	10	30 (Krill meal to Vitamin mixture)	30 (Krill meal to Vitamin mixture)	30 (Krill meal to Vitamin mixture)	10	30 (Krill meal to Vitamin mixture)	
Wheat flour	8				8		
Potato starch	3				3		
Wheat gluten	3				3		
Mineral mixture	3				3		
Vitamin mixture	3				3		
Feed oil*4	14	14	14	14	15	15	
Nutrient content							
Crude protein	43.6	41.1	40.5	38.6	43.0	36.1	—
Crude lipid	21.6	20.3	18.6	18.8	26.2	25.8	—
Crude ash	11.1	10.7	10.0	9.3	10.8	9.1	—
Moisture	11.9	12.9	13.1	12.2	10.9	12.3	—

*1 A control diet.
*2 A mixture of local sardine meal and white fish meal (1: 1).
*3 Low-pro meal (46% crude protein), Showa Sangyo Co.
*4 Pollock liver oil.

Table 2. Extrusion conditions for preparation of a soft-dry pellet containing different levels of soybean meal (SBM)

Process condition	Expt. I				Expt. II	
	SBM in diet				SBM in diet	
	0%	10%	20%	30%	0%	30%
Screw speed (rpm)	250	250	250	250	260	260
Feed rate (kg/h)	1848	1848	1848	1848	1650	1650
Water injection (kg/h)	370	370	370	370	330	330
Material temp. (°C)	73	65	70	71	75	62
Material press (kg/cm^2)	54	56	60	61	52	55
Cutter speed (rpm)	1550	1540	1510	1490	900	900
No. of cutter	4	4	4	4	2	2
Die plate (ϕ: mm)	5	5	5	5	13	13
No. of holes	28	28	28	28	12	12

in this experiment were almost the same as those in the former experiment.[4] The test diets were prepared as soft-dry pellets using a large size of twin extruder (Buhler) (Table 2) as described previously.[4] The size of dry pellets was 7 mm in diameter for juveniles and 13 mm for adult fish. The diets were all prepared in May, about four months before the initiation of feeding experiment, due to the limitation in availability of the twin extruder for preparation of test diet. They were kept in a storehouse at room temperature for about five months in total until abnormal fish with dark coloration were detected in the cages. Thereon the feed was transferred to a cold room for further storage.

The experimental diets were not formulated to be iso-nitrogenous and iso-caloric, thus the protein and lipid contents dropped in proportion to the increment of dietary soybean meal levels, as shown in the analytical data in Table 1. The content

Table 3. Fatty acid composition of total lipids in the experimental diets with soybean meal (SBM)

Fatty acid (area %)	Expt. I SBM in diet				Expt. II SBM in diet	
	0%	10%	20%	30%	0%	30%
12:0	0.3	0.3	0.3	0.4	—	—
14:0	10.1	8.5	9.7	10.4	6.6	8.9
15:0	0.6	0.2	0.2	0.3	0.3	0.6
16:0	24.7	21.6	23.6	22.0	10.4	21.2
16:1	8.6	7.7	8.2	7.6	15.5	7.5
17:0	1.2	1.2	1.2	1.2	0.7	1.2
16:3n-6	0.5	0.5	0.6	0.5	0.7	0.4
16:3n-3	1.1	1.0	1.1	1.0	—	—
16:4n-3	0.1	0.1	0.1	0.1	0.8	1.4
16:4n-1	1.5	1.4	1.4	1.5	1.1	1.0
18:0	3.1	3.0	3.0	2.8	1.0	2.9
18:1n-9	10.6	10.0	10.1	9.5	10.6	13.3
18:2n-9	—	—	—	—	0.7	0.3
18:2n-6	1.5	2.4	2.6	3.0	0.8	2.5
18:3n-6	0.2	0.2	0.2	0.2	—	—
18:3n-3	0.1	0.9	1.0	1.0	0.9	0.9
18:4n-3	0.8	2.4	2.3	2.3	2.8	2.3
20:0	0.1	0.2	0.1	0.1	—	—
20:1n-(11+9)	2.6	2.7	2.3	2.3	2.1	3.6
20:1n-7	0.2	0.2	0.1	0.1	—	—
20:2n-9	0.1	0.2	0.2	0.2	—	—
20:2n-6	0.1	0.1	0.1	0.1	—	—
20:3n-6	—	0.1	0.1	0.1	—	—
20:4n-6	0.9	1.0	0.9	0.9	1.1	1.2
20:3n-3	0.1	0.1	0.1	0.1	—	—
20:4n-3	0.7	0.7	0.7	0.7	—	—
20:5n-3	11.2	12.3	11.2	11.2	14.2	12.9
22:1n-(13+11)	0.9	1.3	1.2	0.9	—	—
22:1n-9	—	0.3	0.3	0.1	—	—
22:4n-9	—	—	—	—	7.6	0.3
22:4n-6	0.1	0.1	0.1	—	1.7	—
22:5n-6	0.1	0.2	0.1	0.1	—	—
22:5n-3	1.5	1.8	1.6	1.6	1.7	1.9
22:6n-3	7.1	8.4	7.0	7.2	7.4	7.5
24:1	0.5	0.6	0.6	0.6	—	—
Σ Monoene	23.4	22.8	22.8	21.1	32.3	26.1
Σ n-6	3.4	4.6	4.7	4.9	4.3	4.1
Σ n-3	22.7	27.7	25.0	25.2	28.5	27.6
Σ n-3 HUFA	20.5	23.2	20.5	20.7	24.0	23.0

of crude protein was about 43% for both control diets and was about 38 and 36% for the juvenile and adult diets containing 30% soybean meal. The lipid content was also lower in the diets containing soybean meal.

The fatty acid composition of the experimental diets analyzed by the method described previously[7] is shown in Table 3. The percentage of 18:2n-6 increased in proportion to dietary soybean meal levels. The percentage of n-3 highly unsaturated fatty acids (n-3 HUFA) did not differ greatly between the diets and was about 20 and 24% in the juvenile and adult diets. The amino acid composition of the juvenile diets analyzed by Japan Food Research Laboratories is shown in Table 4. Among the essential amino acids (EAA) for fish, the content of histidine and methionine decreased slightly while that of arginine increased in proportion to dietary levels of soybean meal. Although the requirement

Table 4. Amino acid composition of the experimental diets for the juvenile yellowtail (Expt. I)

Amino acid (% protein)	SBM in diet				Carp*	Rainbow trout*
	0%	10%	20%	30%		
Arginine	5.26	5.48	5.68	5.72	4.4	4.0
Lysine	7.46	7.47	7.35	7.21	6.0	6.0
Histidine	3.16	2.74	2.68	2.69	1.5	1.8
Phenylalanine	4.12	4.10	4.45	4.54	3.4	3.6
Tyrosine	3.14	3.13	3.22	3.24	2.3	2.4
Leucine	7.46	7.52	7.54	7.64	4.8	5.0
Isoleucine	4.26	4.27	4.37	4.39	2.6	2.8
Methionine	2.84	2.60	2.51	2.49	1.8	2.3
Cystine	0.96	1.02	1.08	1.15	0.9	1.0
Valine	5.17	5.14	5.21	5.08	3.4	3.6
Alanine	6.13	6.16	5.82	5.67	—	—
Glycine	6.25	6.11	5.95	5.59	—	—
Proline	4.32	4.78	4.37	5.13	—	—
Glutamic acid	12.38	13.29	13.98	15.11	—	—
Serine	3.87	3.91	4.10	4.34	—	—
Threonine	4.19	4.12	4.08	4.03	3.8	4.1
Aspartic acid	8.99	9.15	9.48	9.80	—	—
Tryptophan	1.35	1.33	1.33	1.41	0.8	0.6
Crude protein	43.70	41.22	40.70	38.98	—	—

* The essential amino acid requirement of carp and rainbow trout, reported by C. Ogino previously.[8)]

of yellowtail is still unknown, all the diets seemed to satisfy the EAA needs of yellowtail, as inferred from the studies on carp and rainbow trout[8)] (refer to Table 4).

Determination of Digestibility

In order to evaluate the dietary value of soybean meal, apparent digestibilities of protein, lipid, starch, and energy in the experimental diets as well as soybean meal were measured using reference and test diets as described by Cho *et al.*[9)] The reference diet was prepared by supplementing 0.5% chromium oxide as indicator to the control diet used for adult yellowtail. The test diets were prepared by replacing 30, 40, and 50% of the ingredient mixture of the reference diet with the corresponding amount of defatted soybean meal. The diets were all prepared as soft-dry pellets of 13 mm diameter, which were later crushed and sieved to a moderate size for fish.

Yellowtail weighing 250–450 g were stocked into two net cages (2×2×2 m) (150 fish each) located at the Nomo inlet near the Aquaculture Research Laboratory, Nagasaki Prefectural Institute of Fisheries, and fed a commercial yellowtail soft-dry pellet for one week prior to being fed the experimental dry pellets. Then, one lot of fish was fed the reference diet while the other was fed one of the test

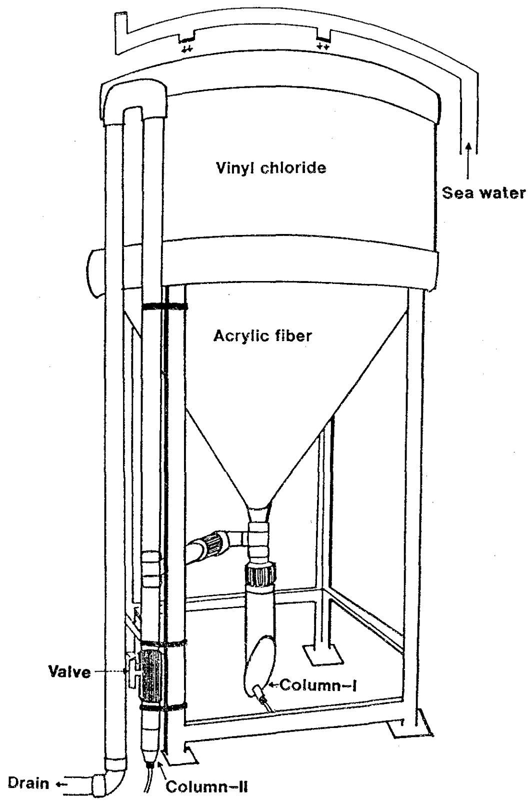

Fig. 1. A feces collection tank.

diets to satiation twice a day (08: 15 and 13: 15). After being fed for 5 days, 30 fish from both lots were transferred in the evening (16: 30) to feces collection tanks, as shown in Fig. 1. The rate of water supply to the tanks was 12–15 *l*/min and the temperature ranged between 16.2 and 18.6°C during the experimental period. At 08: 00 the following day the accumulated feces were gently withdrawn from the base of settling columns I and II separately and kept in a cold

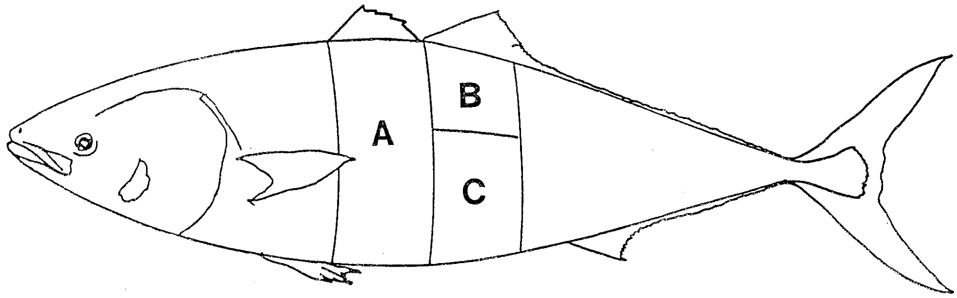

Fig. 2. Muscle samples collected from three portions (A, B, and C) of yellowtail.

Table 5. Results of the juvenile yellowtail feeding with the soft-dry pellets containing different levels of soybean meal (SBM) in the 3×3×3 m net cages (Expt. I)

Diet	No. of fish	Av. body wt. (g)*1		GR*2	FGR*3	DFC*4	Mortality (%)
		Initial	Final				
Preliminary feeding							
	Jun. 27-Aug. 10 '89 (41 day feeding)						
CM diet*5	4000	4.5	100.0	1718	0.86	3.6	22.8
	Aug. 11-Sep. 4 '89 (19 day feeding)						
CM diet	2900	101.7	159.3	57	1.44	3.0	4.6
Experimental feeding							
	Sep. 5-Oct. 13 '89 (31 day feeding)						
0% SBM	627	159.8	331.1	107.2	1.62	3.2	10.7
10% SBM	627	160.1	365.4	128.2	1.59	3.7	9.9
20% SBM	627	159.8	374.2	134.2	1.53	3.8	9.6
30% SBM	627	159.8	384.6	140.7	1.43	3.7	8.8
	Oct. 13-Nov. 17 '89 (27 day feeding)						
0% SBM	380	368.4	607.8	65.0	1.23	2.2	1.8
10% SBM	488	373.0	597.5	60.2	1.35	2.3	1.6
20% SBM	524	380.0	567.5	49.3	1.86	2.7	2.7
30% SBM	516	387.4	591.9	52.8	1.74	2.7	2.1
	Nov. 20-Dec. 11 '89 (16 day feeding)						
0% SBM	302	608.9	688.4	13.1	1.25	1.0	0
10% SBM	310	601.9	662.6	10.1	1.60	1.0	0
20% SBM	310	586.5	664.2	13.3	1.41	1.1	0
30% SBM	310	590.6	633.9	7.3	2.54	1.1	0
	All the period (74 day feeding)						
0% SBM	627	159.8	688.4	319.3	1.40	2.4	11.8
10% SBM	627	160.1	662.6	311.0	1.49	3.0	11.2
20% SBM	627	159.8	664.2	310.8	1.65	3.3	11.8
30% SBM	627	159.8	633.9	296.1	1.62	3.5	10.5

*1 n=Total number of fish.
*2 Growth rate (%).
*3 Feed gain ratio (g feed/g gain).
*4 Daily feed consumption (%).
*5 A commercial soft-dry pellet for yellowtail (0% SBM).

room at −20°C until analysis. The fish were returned to the net cages at 09:00, fed a commercial soft-dry pellet for one week, and had the same treatment with the remaining test diets for feces collection.

The analytical procedures for digestibility calculation were all as described earlier.[10]

Determination of Hematological Characteristics

Blood was sampled from the juvenile and one year old groups on November 1st when the abnormality, characterized as the appearance of dark-colored fish, came to the end. Fish were starved for 24 h prior to blood drawing. Fish were angled and then blood samples were obtained by cardiac puncture with heparinized syringes fitted with 18G needles. The blood samples were kept at 4°C and hematocrit values (Ht) were determined within 2 h after taking the blood. A part of the blood was also centrifuged at 3,000 rpm for 10 min to obtain plasma samples. Alanine aminotransferase (GPT) activity was measured by the UV-kinetic method of Wroblewski-La Du in fresh condition within 24 h. The other constituents and enzyme activities were examined after thawing the frozen plasma. The hemochemical constituents examined were as follows: aspartate aminotransferase (GOT, UK-kinetic method of Karmen), alkaline phosphatase (Al-P, p-nitrophenil phosphate method), glucose (Glu, mutarotase-glucose oxide method), triglyceride (TG, glycerol-3-phopsphate oxidase-DAOS method), phospholipid (PL, choline oxidase-DAOS method), total cholesterol (TCHO, cholesterol oxidase-DAOS method), free cholesterol (FCHO, cholesterol-MEHA method), urea nitrogen (BUN, urease-GIDH method), and total protein (TP, Biuret method). All hemochemical constituents were analysed by the automatic biochemical analyzer CL-7100 (Shimadzu Co.) using commercial clinical investigation kits (Wako Pure Chemical Co.).

Determination of Rheological Properties and K Value

At the end of the feeding experiment five fish were taken from each lot and transferred to the Laboratory of Food Chemistry, Tokyo University of Fisheries, to measure and compare the rheological properties and K value of muscle. The muscles taken from portion B shown in Fig. 2 were used for the determination. The methods for measurement of rheological parameters and K value were those described by Iso *et al.*[11]

Results and Discussion

Feed Performances

Juvenile yellowtail: results of the feeding experiment on juvenile yellowtail are shown in Table 5 and Fig. 3. During the preliminary feeding with a commercial soft-dry pellet for 60 days, fish of 5.5 g on average grew up to 159.3 g and the feed gain ratio was 0.86 in July and 1.44 in August. About 26% of fish were killed by bacterial disease (*Enterococcus seriolicida*) during that time.

The feeding activity was not influenced by substituting fish meal with soybean meal up to 30%, but palatability seemed to be rather high for the diets containing soybean meal, and the feeding rate was proportional to the soybean meal levels. This may partly be due to lower protein and energy contents in the soybean meal diets. Palatability or acceptability of soybean meal is known to vary from species to species. Coho salmon has no problem, but chinook salmon do not accept soybean meal well.[12] Methanol treatment of soybean meal improved

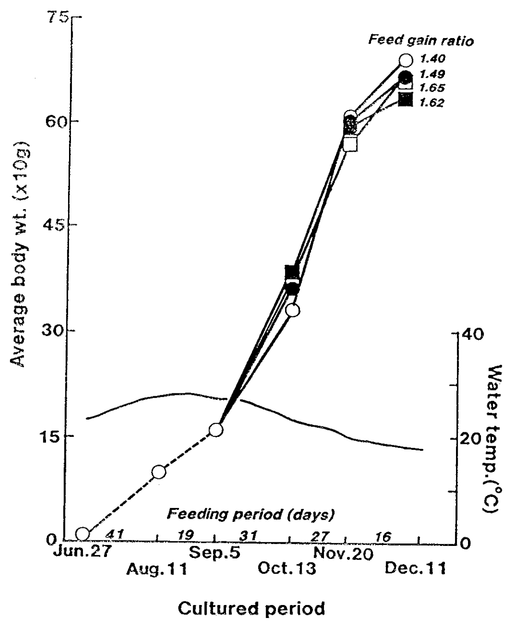

Fig. 3. Growth curves of juvenile yellowtail fed a commercial soft-dry pellet during preliminary feeding (○---○) and experimental soft-dry pellets containing 0 (○—○), 10 (●—●), 20 (□—□), and 30% (■—■) soybean meal, respectively (Expt. I).

growth and feed consumption of 10 g rainbow trout, but the treatment was not required for rainbow trout larger than 30 g or common carp.[13] Channel catfish find soybean meal highly palatable.[14] The dry pellets containing 10–30% soybean meal were first fed to yellowtail and it was found to be palatable and acceptable for both juvenile and adult yellowtail. The high palatability may be due to the inclusion of soybean meal into the highly palatable soft-dry pellets which were prepared by the twin extruder.

Growth of fish as determined three times during the feeding period is also shown in Table 5 and Fig. 3. Growth and feed gain ratio were relatively good in all the experimental groups, regardless of the dietary levels of soybean meal, although the feed gain ratio increased slightly in fish fed the 30% soybean meal diet during November and December. Growth of fish was almost proportional to dietary levels of soybean meal. The average initial body weight of about 160 g rose to 634–688 g after 74 days feeding, being highest in the control group and lowest in the 30% soybean meal group, but without significant difference between the groups. The same ten-

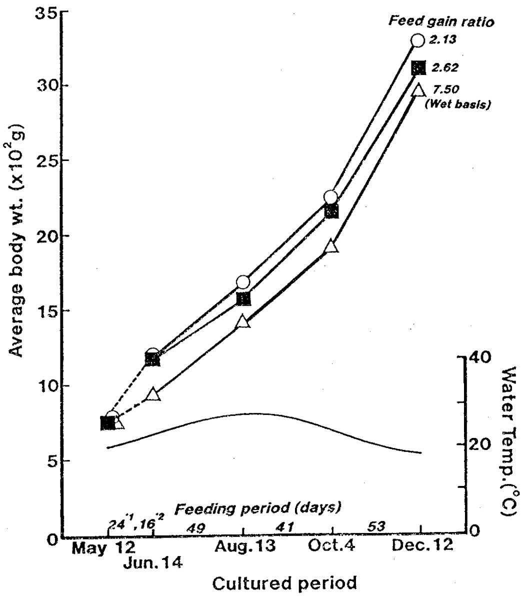

Fig. 4. Growth curves of adult yellowtail fed a commercial soft-dry pellet (○---○, ■---■) or raw sand lance (△---△) during preliminary feeding and experimental soft-dry pellets containing 0% (○—○), 30% (■—■) soybean meal, or raw sand lance (△—△), respectively (Expt. II).

Table 6. Results of the adult yellowtail feeding with the soft-dry pellets containing different levels of soybean meal (SBM) or raw sand lance in the 3×3×3 m net cages (Expt. II)

Diet	No. of fish	Av. body wt. (g)*		GR*	FGR*	DFC*	Mortality (%)
		Initial	Final				
Preliminary feeding							
May 12-Jun. 13 '89 (24 day feeding for CM diet and 16 day for sand lance)							
CM diet*	220	786	1134	44.4	1.67	2.5	0.9
CM diet	219	791	1157	46.3	1.60	2.5	0
Sand lance	220	738	935	26.7	2.77	4.1	0
Experimental feeding							
Jun. 14-Aug. 11 '89 (49 day feeding)							
0% SBM	133	1190	1670	40.0	2.79	1.9	0
30% SBM	135	1170	1560	33.3	3.22	1.9	0.7
Sand lance	168	942	1410	49.5	8.86	7.1	1.2
Aug. 13-Oct. 4 '89 (41 day feeding)							
0% SBM	128	1680	2230	33.0	2.36	1.6	3.1
30% SBM	130	1560	2140	37.0	3.17	1.6	26.9
Sand lance	162	1410	1910	35.8	7.66	5.5	6.2
Oct. 4-Dec. 12 '89 (53 day feeding)							
0% SBM	100	2290	3260	42.4	1.48	0.9	4.0
30% SBM	90	2160	3080	42.6	1.88	1.2	2.2
Sand lance	115	1960	2930	49.7	6.35	4.4	2.6
All the period (143 day feeding)							
0% SBM	133	1190	3260	169.9	2.13	1.4	6.0
30% SBM	135	1170	3080	161.7	2.62	1.4	28.2
Sand lance	168	942	2930	208.5	7.50	5.4	8.9

* See the footnote of Table 5.

dency was also observed in feed gain ratio ranging from 1.40 in the control to 1.65 in the 20% soybean meal fed groups. As shown in Table 1, the protein and lipid contents in the diets were reduced inversely to dietary soybean meal levels, since the protein and energy levels were not adjusted to be equal among the experimental diets. This might be the reason for the differences in growth and feed gain ratio between the control and the soybean meal fed groups. Thus, it may be possible to improve the dietary value of the soybean meal diets, especially the 30% component diet, by elevating protein and energy levels in the diet. Cumulative mortality was about 11% in all the experimental groups, and was mostly due to bacterial disease (*Enterococcus seriolicida*) during September and October.

Adult yellowtail: Palatability or acceptability in terms of feeding activity did not vary due to the inclusion of 30% soybean meal in the diet as already observed in the juvenile yellowtail. The average body weight recorded three times during the feeding period of 143 days is shown in Fig. 4, and the feed gain ratio in Table 6. Fish fed on diets with or without soybean meal grew up to 3,260 and 3,080 g on average, while those on sand lance grew 2,930 g. The growth rate was highest in the control group, but the difference in feed performance between the control and the 30% soybean meal diet was presumed to be due to the lower protein and energy contents of the latter diet as observed in juvenile yellowtail. Modifications in dietary value as suggested for juveniles earlier might also be successful for adults. However, the difference of the final body weight between the control and the sand lance groups was almost the same as that of the initial body weight, suggesting that there was no marked difference in dietary value between the control dry pellet and sand lance. Their feed gain ratios were respectively 2.13, 2.62, and 7.50, inferior to those recorded in the juvenile yellowtail. This may be partly due to feed losses caused by the high feeding activity of one-year-old fish kept in the small net cages and partly to higher energy expenditure of the fish than juveniles. During the initial 49 days of feeding there was no marked mortality in any of the groups, but a high mortality of 26% due to becterial disease (*Pasteurella piscicida*) was observed in the group fed the 30% soybean meal diet during August and October. This

Table 7. Proximate composition of the muscles from three portions* of the juvenile and adult yellowtail fed the soft-dry pellets containing different levels of soybean meal (SBM) or raw sand lance (%)

Diet	Crude protein Portion			Crude lipid Portion			Crude ash Portion		
	A	B	C	A	B	C	A	B	C
Expt. I									
	Dec. 20 '89 (n=3)								
0% SBM	23.2	23.3	21.8	12.8	12.6	19.2	2.7	2.7	2.3
10% SBM	23.2	23.2	22.4	11.8	14.0	16.2	2.8	2.7	2.8
20% SBM	23.5	24.2	23.1	8.3	9.5	12.0	2.8	2.8	2.4
30% SBM	23.4	23.9	22.2	13.7	13.4	17.1	2.8	2.7	2.2
Expt. II									
	Aug. 11 '89 (n=3)								
0% SBM	23.4	23.8	22.2	10.6	10.0	14.6	2.1	2.3	2.1
30% SBM	23.4	23.6	22.8	10.9	9.5	13.6	2.4	2.4	2.4
Sand lance	23.1	23.9	23.8	10.1	7.7	11.0	1.9	2.2	2.1
	Oct. 4 '89 (n=3)								
0% SBM	19.4	19.3	17.7	17.8	17.0	24.4	1.9	2.1	1.8
30% SBM	20.1	20.3	17.3	15.4	13.7	21.7	2.2	2.3	2.0
Sand lance	20.7	21.2	19.4	13.3	10.7	18.7	2.2	2.1	1.8
	Nov. 29 '89 (n=3)								
0% SBM	18.9	19.2	19.1	22.1	18.4	25.4	2.6	2.7	2.7
30% SBM	20.7	21.1	19.6	16.3	13.7	19.6	2.5	2.4	1.9
Sand lance	20.6	21.0	18.9	16.2	13.1	23.6	2.5	2.5	2.5

* See Fig. 2.

group probably had a lower resistance to the bacterial disease.

Lipid and Protein Contents of Muscle

The protein and lipid contents of muscles sampled from three portions (A, B, and C) marked in Fig. 2 is shown in Table 7.

Juvenile: There was no marked difference in the protein content between the dietary treatments and three portions of each group. In all the groups the lipid content was high in sample C of ventral muscle and was inversely proportional to dietary levels of soybean meal. This might be due to a reduction in protein and energy levels on replacing fish meal with soybean meal.

Adult yellowtail: The protein content did not differ greatly in any part of the experimental groups, and exhibited a seasonally-dependent decreasing tendency from summer to winter in all the groups. Correspondingly, the lipid content increased in winter due to growth and was also high in sample C in all the groups as observed in the juveniles. The lipid level was reduced by the inclusion of 30% soybean meal in the diet.

Digestibility of Nutrients in Test Diets and Soybean Meal

Digestibility determined separately, using the feces collected from the settling columns I and II, is shown in Table 8. There was no marked difference in protein or carbohydrate digestibility in the feces from columns I and II. Digestibility of protein in the control (reference) diet was about 85% and was not reduced on replacing fish meal with 30, 40, or 50% soybean meal. Lipid digestibility determined from the feces collected in column II was 89% for the reference diet and was also not influenced by dietary soybean meal levels, except for a low of 74% for the 50% soybean meal diet. Digestibility of carbohydrate was also low in the 50% soybean meal diet. Thus, energy digestibility was reflected by lipid and carbohydrate digestibility, ranging from 82% in the reference diet to 75% in the 50% soybean meal. The control diet had a digestible energy value of 4.1 kcal/g, while the 50% soybean meal diet had 3.6 kcal/g.

Digestibility of the soybean meal protein was about 86% in the diet containing 30% soybean meal, and was also not influenced by the elevation of soybean meal levels from 30 to 40 or 50%. The value was higher than those obtained in black seabream and channel catfish, but comparable to those in rainbow trout and carp.[15] Relatively high protein digestibility obtained in this experiment may partly be due to extrusion treatments as reported by Kaushik.[16] Digestibility of carbohydrate in the soybean meal was 55 and 60% in the 30 and 40% dietary levels, and was reduced to 45% at the 50% level. The energy digestibility was 75% for the 30 and 40% soybean meal diets and 68% for the 50% level.

Hematological Characteristics

The results of hemochemical assessments for juvenile and adult yellowtail are shown in Figs. 5 and 6, respectively.

The actual measurements of hemochemical constituents of fish in each group were diverse.

Table 8. Apparent digestibility (AD) of nutrients in the experimental diets containing different levels of soybean meal (SBM) and in soybean meal*1 (%)

Diet	AD						AD		
	Reference and test diet				GE*2 (kcal/g)	DE*3 (kcal/g)	Soybean meal		
	Protein	Lipid	Carbo-hydrate	Energy			Protein	Carbo-hydrate	Energy
0% SBM	86		65	82	5.0	4.1	—	—	—
	(87)	(89)	(66)						
30% SBM	86		62	80	4.9	3.9	86	55	75
	(87)	(87)	(62)						
40% SBM	85		63	79	4.9	3.9	84	60	75
	(86)	(87)	(64)						
50% SBM	85		55	75	4.8	3.6	84	45	68
	(85)	(74)	(55)						

*1 Values in ( ) were obtained by the feces collected from the column II, and others were all from the column I.
*2 Gross energy.
*3 Digestible energy.

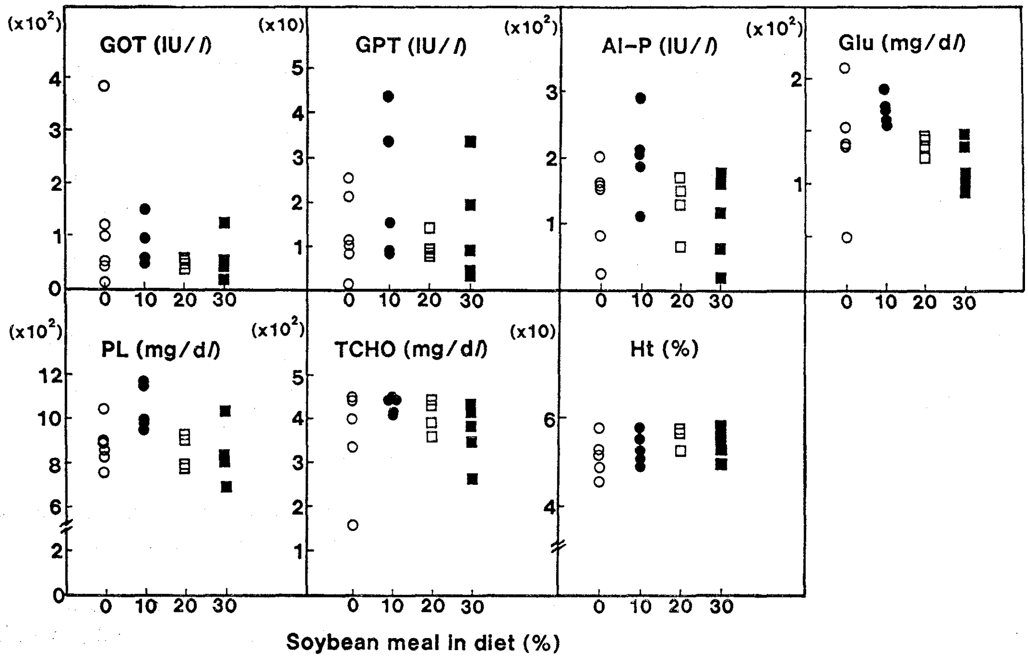

Fig. 5. Results of hemochemicala ssessments in the juvenile yellowtail fed experimental soft-dry pellets containing 0 (○), 10 (●), 20 (□), and 30% (■) soybean meal, respectively (Expt. I).

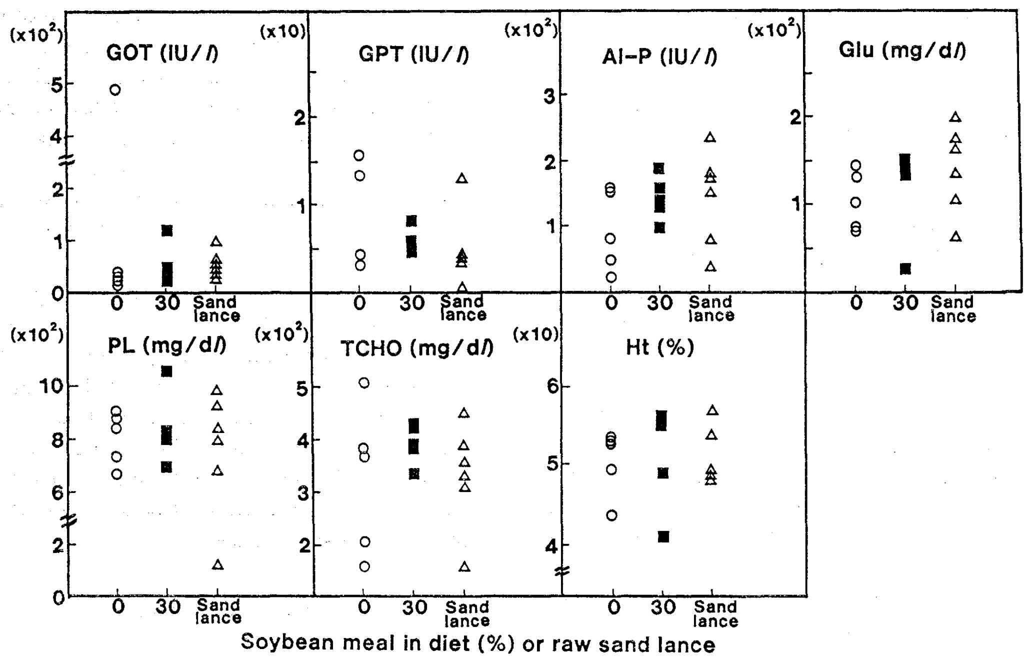

Fig. 6. Results of hemochemical assessments in the adult yellowtail fed experimental soft-dry pellets containing 0% (○), 30% (■) soybean meal, or raw sand lance (△), respectively (Expt. II).

Table 9. Rheological parameters of the muscles from the juvenile and adult yellowtail fed the soft-dry pellets containing different levels of soybean meal (SBM) or raw sand lance*

Diet	Instantaneous elastic modulus $E_0 \times 10^{-5}$ (dyn/cm^2)	Viscosity $\eta_1 \times 10^{-7}$ (poise)	Rupture strength $R \times 10^{-4}$ (dyn/cm)	*K* Value (%)
Expt. I				
0% SBM	12.1±0.02	2.9±1.27	25.6±16.71	17.0±0.78
10% SBM	14.6±4.63	4.3±0.52	24.3±13.42	15.9±1.29
20% SBM	12.0±1.08	2.9±0.50	25.9±18.84	26.9±0.23
30% SBM	10.0±1.46	2.7±0.28	21.4± 6.02	14.2±0.11
Expt. II				
0% SBM	6.3±0.29	1.0±0.06	25.7±52.84	5.0±1.17
30% SBM	5.3±0.51	1.4±0.02	21.4± 9.90	2.6±0.24
Sand lance	6.5±0.73	1.6±0.32	27.2±32.86	2.4±0.75

* Values are means±S.D. (n=5).

Fluctuation of GOT, GPT, and Al-P activities and Glu, TCHO, and PL levels were sporadically observed in all the groups of both juvenile and adult yellowtail. Malfunction of the liver in yellowtail due to unsuitable diet revealed low levels in lipid components and Glu of plasma: TCHO, <250 mg/d*l*; PL, <800 mg/d*l*; Glu, <80 mg/d*l*.[17] GOT and GPT activities increased when hepatocytes were damaged.[18] The Al-P activity and Glu level were elevated due to enterococcal infection.[19] The fluctuation in our data is probably not related to the inclusion of SBM in the diet, but has a bearing on the physiological conditions induced by feed related abnormality during the first month of feeding or the subsequent enterococcal infection.

Rheological Properties

The rheological parameters of the muscles from juvenile and adult yellowtail are shown in Table 9. In general, elasticity and viscosity together with rupture strength were higher in the muscle of juvenile fish than in adult fish.

In juvenile fish the instantaeous elastic modulus was highest in fish fed the diet containing 10% soybean meal and lowest in those on the 30% soybean meal diet. There was no marked difference between the fish fed the control and 20% soybean meal diets. The values for viscosity also showed the same tendency, being highest in fish fed the 10% soybean meal diet. The rupture strength ranged from 21.4 to 25.9 dyn/cm in the 30 and 20% soybean meal groups, respectively. There was no marked difference in the K value except for the value of 26.9 obtained with the muscle from the 20% soybean meal diet group. The value was very high, but was still within the range of edible condition as raw flesh (*sashimi*).

In adult yellowtail the muscle elasticity was slightly low in the 30% soybean meal group, but not markedly different between the control and raw sand lance groups. The viscosity was lowest in the control and was improved by the inclusion of 30% soybean meal. The rupture strength ranged from 21.4 dyn/cm in the 30% soybean meal to 27.2 dyn/cm in the raw sand lance group. These values were almost the same as those in the juvenile fish. On the other hand, the K values were significantly lower than in the juvenile fish, showing that the conditions of fish transportation from Owase to Tokyo were better for the adult fish. It could therefore be suggested that there was no significant effect of dietary soybean meal levels on the flesh quality of either juvenile or adult yellowtail.

Thus, the results of the present study have demostrated that soybean meal can be included as a protein source up to 30% in place of fish meal (substitution of about 55% fish meal) in soft-dry pellets for both juvenile and adult yellowtail without any marked ill effects, although the elevation of protein or energy levels is required to obtain growth and feed efficiency comparable to the control fish meal diet.

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