PROPERTIES OF DIFFERENT FISH PROCESSING BY-PRODUCTS FROM POLLOCK, COD AND SALMON

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ABSTRACT

Individual fish processing waste stream components can be used to make feed ingredients or other products. Waste stream components obtained from commercial fish processing plants included heads, viscera, frames, and skins from Alaska pollock (Theragra chalcogramma) *and Pacific cod* (Gadus macrocephalus)*; and heads, and viscera from pink salmon* (Oncorhynchus gorbuscha). *The protein content of heads from all three species ranged from 13.9 to 16.4%; and the fat content ranged from 0.9 to 10.9%. Viscera protein content ranged from 13.0 to 15.3%, and the fat content from 2.0 to 19.1%. After heating to 85C the percent soluble protein in salmon heads was different* ($P < 0.05$) *from pollock or cod heads. Percent soluble protein of pollock and cod skin increased 8 fold* ($P < 0.05$) *after the 85C heat treatment. Connective tissue content was calculated from chemical determination of hydroxyproline content, and large differences in percent connective tissue content were found (1% for pollock viscera to 46% for skin). Estimated rat PER values ranged from a low of 2.1 for skin to a high of 3.1 for viscera and fillet samples* ($P < 0.05$).

INTRODUCTION

Over 65% of the total fish harvested for human consumption in the U.S. come from Alaskan waters. The three most abundant species of fish caught in these waters are Alaska pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*) and pink salmon (*Oncorhynchus gorbuscha*). The total harvest of these three types of fish was estimated at 1.4 million metric tons in 2000

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(NMFS 2000; ADFG 2000) or about 74% of the commercial fish harvest from these waters. The amount of fish processing waste ranges from 66% for producing pollock fillets to 27% for producing headed and gutted salmon (Crapo *et al.* 1993). Fish processing wastes from some surimi operation have been greater than 80%. Because the fish are being processed for human consumption the fish by-products are initially of high quality and can be converted into a number of products.

The most common procedures used in pollock and cod processing is to first mechanically remove the head, usually followed by removal of the viscera (roe and egg products of value are saved and depending on markets the cod milt and stomachs can be saved). The next step is mechanical removal of fillets with skin attached from the headed and gutted fish and then skins are mechanically removed from the fillets using Baader or similar equipment. Because the waste components are removed in separate operations, it is possible to obtain fish by-products consisting of all heads, frames, viscera, and skins. Bone is present in the frames and heads by-product components. Salmon processing is similar in that the heads are removed and viscera removed (salmon roe is separated); however, most pink salmon will be canned or frozen for markets as headed and gutted fish.

Fish harvesters and processors want to maximize profitability and fish value by developing markets for fish by-products and reduce disposal costs. A large use of fish processing wastes is in the production of fish meals and fish oils for aquaculture and animal feeds. There is a need for specialized aquaculture feed ingredients that can be blended with plant proteins to enhance the nutrition and palatability properties. It is possible to collect individual waste stream components (heads, frames, viscera, and skins) and devise methods for using them as feed ingredients or other products.

There are chemical and biochemical differences between fish species (Stansby 1976; Krzynowek *et al.* 1989), which translates into species differences in the composition of fish waste components and by-products. Basic data characterizing waste stream components are not available; however, the book by Kizevetter (1971) contains data from the 1950s and 1960s on some aspects of these fish and selected fish part composition as well as differences due to gender, season of the year, maturity, etc. Other scientists have provided useful values such as viscera (Freeman and Hoogland 1956; Dong *et al.* 1993), and pollock heads and frames (Babbitt 1990). Differences in techniques, sampling procedures, and sources of tissues (often different from those of the Alaskan fisheries) make direct comparisons of data difficult. There are no complete sets of data in the literature that can provide insight into the composition and properties of fish processing waste stream components.

Opportunities for enhanced utilization of fish processing wastes may lie in specialty feeds, human food uses, fertilizers, hydrolysates, and in using

individual waste stream components to create value added products. The objective of this study was to determine the composition and evaluate the protein solubility and connective tissue content of the individual waste stream components from commercial fish processing operations for the three species harvested in the greatest amounts in Alaskan waters (Alaska pollock, Pacific cod, and pink salmon).

MATERIALS AND METHODS

Fish By-products

Fish, fillets, and fish by-products were obtained from commercial fish processors in Kodiak, Alaska during the middle of a commercial fish harvesting and processing season. Whole fish, heads, viscera, frames, fillet and skins for both Alaska pollock and Pacific cod were obtained over a one week period in February. Whole fish, heads, viscera, and headed and gutted pink salmon were obtained over a one week period in August. Sets of whole fish, heads, viscera, frames, fillet and skin were taken from one of two processing plants for each species on three separate days to collect fish harvested from different areas. There are three replicates for each part by specie identified as samples collected on separate days. A total number of 48 samples (18 for pollock, 18 for cod and 12 for salmon) were collected.

The harvested fish were delivered on ice and/or refrigerated sea water by fishing vessels to the processors dock. Pollock and cod were first placed on a belt and heads mechanically removed, and viscera separated from the body by hand. Fillets were mechanically removed from the headed and gutted fish which was followed closely by mechanical removal of the skins from the fillets. Samples included whole fish, heads, viscera, frames from which the fillets were removed, skinless fillets (not trimmed) and skins. The viscera for cod had the roe and milt removed, and the pollock viscera contained the roe and milt. For the pink salmon the process was similar with fresh fish delivered on ice and/or refrigerated sea water and then placed on a belt and the head mechanically removed followed by removal of the viscera. Most pink salmon are either canned or sold as frozen headed and gutted fish; therefore, samples collected included whole fish, heads, viscera and headed and gutted fish. Salmon viscera had the roe removed. Fresh water was used in all processing plant operations.

Fish and fish by-products were collected from the processing plants in the morning and processed immediately or frozen in a -30C blast freezer. Fish and fish by-products were first cut into small pieces, ground though a 12 mm plate three times, and then ground through a 6 mm plate two additional times. Aliquots were taken and stored in Nalgene bottles at -80C until analyzed.

Compositional Analyses and Properties

Moisture content of the ground fish was determined on 3 g dried at 103C for 17 h in triplicate. Ash content was determined in triplicate on either 3 g of wet or 1 g of freeze dried ground fish (Virtis Freeze Dryer model BT 3.3 ES). Ground fish samples were placed in a muffle furnace at 550C for 6 h. Lipid content was determined in triplicate from freeze dried ground fish using a Leco FA-100 analyzer and CO_2 supercritical fluid extraction method as outlined in the Leco FA-100 Fat Analyzer Instruction Manual No. 200-522, 1998. Nitrogen content was determined in triplicate using a Leco FB-2000 nitrogen analyzer and combustion method as outlined in the Leco FP-2000 Nitrogen Analyzer Instruction Manual No. 200-613, 1999. Protein content was calculated as percent nitrogen times 6.25.

The pH of the ground fish was determined by modifying the method of Riss *et al.* (1983). Two grams of ground fish was placed in 40 mL of distilled water at 25C and homogenized at 11,000 RPM using an Ultra Turrax Model T25 homogenizer for 30 s. The pH was determined using a standardized Beckman pH Meter Model number 350. Conductivity of equivalent solutions was determined using a Corning Model 411 conductivity meter at 23C.

Percent protein solubility was determined by a modification of the protein dispersibility index (Batal *et al.* 2000) before and after heating the ground fish samples to 85C. Two 2 g aliquots of each sample of ground fish were weighed and placed in Pyrex tubes. One sample was used directly at 23C and the other heated in a 85C water bath for 30 min and cooled. Samples were transferred to plastic tubes with 40 mL of 30C distilled water and homogenize for 1 min using a Ultra Turrax T25 at 11,000 RPM. Samples were then placed in a water bath at 30C for 30 min and spun in a Beckman Model 21 centrifuge at 10,000 × g for 15 min at 20-25C. An aliquot of the aqueous layer was removed and frozen until the protein content was determined. The protein content of the aqueous layer was determined using the (Sigma procedure No. 690) modified biuret system of the Ohnishi and Barr (1978) method with bovine serum albumin as the standard. The percent soluble protein was calculated from the ratio of total milligrams of soluble protein in the aqueous layer/total milligrams of protein times 100.

The amount of connective tissue in the ground fish was calculated by determining the amount of hydroxyproline using the AOAC official method 990.26 (AOAC 2000). Freeze dried ground fish (0.25 g) were hydrolyzed with 3.5 M sulfuric acid for 17 h at 104C, dilutions made with distilled water, and the hydroxyproline content determined for each of the 48 samples. All reagents and chemicals were purchased from Fisher Scientific Company and the standard curve was generated using hydroxyproline. Calculations used a collagenous connective tissue hydroxyproline content value of 12.5% (AOAC 2000) and a

nitrogen to protein conversion factor of 6.25. The estimated rat protein efficiency ratio (PER) was calculated using the equation (Y = -0.02290 X + 3.1528 where Y is the estimated PER and X is the collagen content) developed by Lee *et al.* (1978).

Statistics

Factorial ANOVA procedure were used with Statistica release 6, series 0102 (see www.statsoft.com) software with two factors (fish species and by-product parts) and eleven dependent variables (percent moisture, protein, fat, and ash, pH, conductivity, protein solubility at 30 and 85C, hydroxyproline content, percent connective tissue, and estimated rat PER). The Multivariate Tests of significance for species, parts, and species*parts were all significant ($P<0.00001$). Post hoc analysis used the Duncan test and the level of significance used was $P<0.05$. The t-test was used to compare selected protein solubility values (no heat treatment vs 85C heat treatment) with significance reported at $P<0.05$. Salmon H & G fish were not included in any of the statistical analysis because comparable pollock and cod products are not produced in high volume.

RESULTS AND DISCUSSION

Waste Stream Components

Alaska pollock and Pacific cod samples included whole fish, fillets, heads, viscera, frames and skins (Table 1). Fish processing waste components were the heads, frames, viscera, and skins. Fillets provided common tissues for which many literature values are available and whole fish were also taken in part to provide reference values. Fish processing waste components that were not sampled would include small quantities of trimmings and bone from the fillet trimming operations.

A large number of variables can affect the composition of the whole fish and its components including, fish size, time of harvest, gender, and other environmental factors. Two additional factors affecting the composition of fish heads are the amount of flesh and muscle remaining with the head after it is removed from the rest of the fish and the amount of viscera components (e.g. heart and pieces of liver and digestive tract) that remained attached to the head. In this study the visceral components were removed from the heads before preparation. The frames consist of the backbone, fins, tail and some skin and muscle. The type of filleting machine and its adjustments can alter the amount of tissues that remain attached to the frame. Viscera is usually removed after the head is severed from the body and then valuable viscera components such as roe

TABLE 1.
PROXIMATE ANALYSIS OF FISH PROCESSING BY-PRODUCT STREAM COMPONENTS[1]

	ALASKAN POLLOCK				PACIFIC COD				PINK SALMON			
	Moisture %	Protein %	Fat %	Ash %	Moisture %	Protein %	Fat %	Ash %	Moisture %	Protein %	Fat %	Ash %
Whole Fish	78.1^{Auw} 1.7	16.4^{Auvw} 0.3	3.6^{Au} 1.4	2.6^{Au} 0.4	79.4^{Auwy} 0.8	16.7^{Auxz} 0.5	1.9^{Au} 0.1	2.6^{Av} 0.1	71.7^{Bx} 0.9	20.3^{Bx} 0.5	6.9^{Bx} 0.5	2.0^{Bx} 0.1
Fillets	82.3^{Awx} 0.3	17.5^{Auw} 0.4	0.5^{Aw} 0.1	1.1^{Avyz} 0.1	82.3^{Auwx} 0.2	18.2^{Auz} 0.4	0.5^{Au} 0.0	1.3^{Aw} 0.1	ND	ND	ND	ND
Heads	79.9^{Auwx} 0.7	15.2^{Auv} 0.3	1.2^{Aw} 0.5	4.6^{Aw} 0.2	80.2^{Auwxy} 0.4	16.4^{Auwxz} 0.8	0.9^{Au} 0.3	4.2^{Bx} 0.2	71.8^{Bx} 1.5	13.9^{By} 1.0	10.9^{By} 0.4	3.4^{Cy} 0.3
Viscera	63.5^{Av} 2.8	15.2^{Auv} 1.4	19.1^{Av} 1.3	1.6^{Avz} 0.1	76.5^{Bvy} 2.1	13.0^{Bv} 0.4	8.1^{Bv} 2.5	2.0^{Bv} 0.1	81.2^{Cy} 0.7	15.3^{Az} 0.4	2.0^{Cz} 0.3	1.7^{Az} 0.1
Frames	80.9^{Auwx} 0.8	16.3^{Auvw} 0.9	0.9^{Aw} 0.4	3.4^{Ax} 0.5	81.0^{Auwxy} 1.0	15.8^{Aux} 0.3	0.6^{Au} 0.1	3.9^{Ax} 0.7	ND	ND	ND	ND
Skin	78.2^{Auw} 2.9	25.0^{Ax} 2.9	0.4^{Aw} 0.1	0.7^{Ayz} 0.2	78.1^{Auvxy} 1.3	24.5^{Ay} 1.8	0.3^{Au} 0.1	2.0^{Bv} 0.5	ND	ND	ND	ND
H & G	ND	ND	ND	ND	ND	ND	ND	ND	72.9 1.5	20.6 2.3	6.0 1.1	1.8 0.1

[1] Values are means of three replications; standard deviations are listed below.
ND is not determined
^{ABC} Superscripts with different letters within a row for similar analysis are different ($P<0.05$).
^{uvwxyz} Superscripts with different letters within a column are different ($P<0.05$).

are separated generally by hand. Factors that affect viscera composition include the removal of components such as roe, milt and stomachs, and the amount of viscera left attached to the head. In this study, the milt and roe were removed from the cod viscera, but the roe (pollock roe is normally removed from the viscera) and milt are included in the pollock viscera. Another major factor affecting the composition of the viscera is the fat content of the livers, which can vary from 22 to over 50% fat on a weight basis for pollock. The liver as a percent of fish weight varies during the different seasons of the year. Skins mechanically removed from fillets can vary in the amount of muscle and other tissue remaining attached to the skin. Pollock and cod skins used in this study were removed from the fillets using a shallow skinning procedure resulting in little flesh remaining attached to the skin.

Pink salmon are harvested during a single short summer season. In this study, whole salmon and by-product components were obtained from two processing plants in which the fish were mechanically headed and viscera removed. The heart and attached viscera components were removed from the heads before grinding. During processing, viscera was manually removed from the body cavity and roe was separated before samples were taken. Most pink salmon are canned or frozen after being headed and gutted (H & G); therefore, samples of the H & G fish were taken.

Composition

The moisture, protein, fat and ash content of the Alaskan pollock, Pacific cod and pink salmon samples on a wet tissue basis are listed in Table 1. Pollock and cod whole fish exhibited similar ($P>0.05$) protein contents (16.4 and 16.7%) and relatively low fat contents (1.9 to 3.6%). Whole salmon exhibited a higher ($P<0.05$) fat (6.9%) and protein (20.3%) content than either pollock or cod. Composition of whole salmon was similar to that of the salmon H & G. The values for pollock fillet protein (17.5%), fat (0.5%), and ash (1.1%) content from this study are in agreement with published (USDA 2001) values for pollock fillet (protein 17.2%, fat 0.8%, ash 1.2%). Heads from pollock and cod exhibited similar protein contents (15.2%, 16.4%), low fat contents (0.9, 1.2%), and high ash contents (4.2%, 4.6%). Salmon heads were lower ($P<0.05$) in protein and ash contents than pollock and cod heads, but the salmon head fat content was approximately ten fold greater at 10.9%.

The protein composition (Table 1) of pollock, cod and salmon viscera ranged from 13.0 to 15.3% and the ash content ranged from 1.6 to 2.0%. There were large differences ($P<0.05$) in the viscera fat content among the three species. Salmon viscera was much lower ($P<0.05$) in fat content (2.0%) than either pollock (19.1%) or cod (8.1%) viscera. The high fat content observed in pollock and cod viscera and the low fat content observed in other pollock and

cod tissues are consistent with viscera containing the major fat storage sites (liver, etc.). Major fat storage sites for pink salmon are in the head (Table 1). Pink salmon skin is another fat storage site and a single sample of several pink salmon skins obtained at the same time as other salmon tissues contained 7.5% fat. A single pink salmon fillet from three skinless fillets (obtained at the same time as other salmon fillets) contained 2.3% fat.

The protein content of skins from pollock and cod were 25.0 and 24.5%, respectively (Table 1). These protein values are high and probably reflect the conversion factor of 6.25 used in the calculation of percent nitrogen to protein; also, the samples are not pure skin but have small amounts of attached tissue. Lower conversion values are reported for yellow perch fillet (Sosulski and Imafidon 1990), gelatin and other foods (Pomeranz and Meloan 1994). The fat content of pollock (0.4%) and cod skins (0.3%) are low and a difference ($P<0.05$) in ash content between pollock and cod was noted.

There were many differences ($P<0.05$) in the composition of by-product components within a species (Table 1). Pollock and cod viscera exhibited the highest fat contents and pollock and cod skins exhibited the highest protein contents ($P<0.05$). The ash contents of pollock and cod, heads and frames were greater ($P<0.05$) than other waste components. Salmon heads exhibited a higher ($P<0.05$) fat and ash content than salmon viscera or whole fish.

Percent Protein Solubility and pH

The pH and conductivity determinations for fish tissues are presented in Table 2. The effects of both pH and temperature on the solubility of proteins and other protein properties are well documented (Schnepf 1992) and the pH of fish tissues may be altered by a number of factors. As a generality, minimum solubility is observed at a pH close to the isoelectric point, and increased solubility is observed at more acid or basic pH values. The pH values ranged from a high of 7.80 to a low of 6.80 for the collected fish tissues. There were some pH differences between by-product components within a species. Viscera pH values for the three species were in a narrow range from 6.96 to 7.10 ($P>0.05$). Onodenalore and Shahidi (1996) reported the lowest protein solubility between pH 5 to 8 for shark soluble protein, which is the range of the pH values determined in this study.

The pH of whole salmon and salmon heads was lower ($P<0.05$) than comparable pollock and cod samples (Table 2). The pH of whole salmon was 6.75 and similar to the 6.57 value for salmon H & G. Pollock and cod fillets exhibited pH values of 7.20 and 6.80 ($P<0.05$), similar to the 6.60 pH of salmon fillets (determined on a single sample of fillets). Ionic strength was previously demonstrated to affect protein solubility and other properties of proteins. After being caught at sea, fish are often stored in refrigerated sea

TABLE 2.
CONDUCTIVITY AND pH OF BY-PRODUCT STREAM COMPONENTS[1]

	Species	Whole Fish	Heads	Viscera	Frames	Skin	Fillet	H&G
pH	Pollock	7.73^{Au}	7.80^{Au}	6.97^{Av}	7.87^{Au}	6.97^{Av}	7.20^{Av}	ND
		0.25	0.10	0.15	0.06	0.12	0.10	
	Cod	7.73^{Au}	7.67^{Au}	7.10^{Avwy}	7.80^{Au}	7.37^{Bvy}	6.80^{Bvw}	ND
		0.40	0.06	0.00	0.20	0.06	0.17	
	Salmon	6.75^{Bx}	7.13^{By}	6.96^{Axy}	ND	ND	ND	6.57
		0.02	0.05	0.06				0.04
Conductivity uS/cm	Pollock	720^{Auvwz}	747^{Auvw}	703^{Auvwz}	592^{Avxz}	249^{Ay}	612^{Auvxz}	ND
		14	71	69	65	101	59	
	Cod	878^{Bu}	754^{Av}	980^{Bu}	643^{Av}	365^{Bw}	668^{Av}	ND
		129	30	31	28	37	32	
	Salmon	627^{Ax}	604^{Bx}	657^{Ax}	ND	ND	ND	548
		40	62	29				24

[1] Values are means of three replications; standard deviations are listed below.
ND is not determined.
^{ABC} Superscripts with different letters within a column category are different ($P<0.05$).
^{uvwxyz} Superscripts with different letters within a row are different ($P<0.05$).

water before delivery to the processors. Conductivity values were determined as an indicator of the salt content of fish tissues. The salt values reported in Table 2 indicate only small differences in the ionic strength of the by-product components except for the pollock and cod skins which exhibited lower conductivity values.

Solubility is an important property in the utilization of proteins. An example is in aquaculture feeds where solubility, stability and palatability properties are affected by protein solubility characteristics. Effects of heat on protein solubility are important considerations in the processing of fish wastes, because the wastes are usually heated to halt microbial and enzymatic degradation and as part of the concentration process. In this study, percent protein solubility values were determined in unheated samples and after heating samples to 85C (Table 3). The 85C values reflect the protein solubility after heating to a temperature that is a little lower than that used in the initial heating step of fish meal production (Windsor and Barlow 1981).

As shown in Table 3 for both pollock and cod fillets, the percent soluble protein after the 85C heat treatment was reduced approximately 2 to 3 fold from the unheated fillets ($P<0.05$). This reduction is consistent with a loss of solubility due to heat denaturation and aggregation of myofibrillar and other proteins. The protein solubility of the unheated pollock and cod skin samples was very low, but after the 85C heat treatment protein solubility increased 9 to 13 fold ($P<0.05$). Most of the increased solubility was attributed to skin collagen and connective tissues undergoing extensive molecular rearrangements and becoming soluble at 85C. Both head and frame samples from pollock and cod exhibited similar ($P>0.05$) percent protein solubility before heat treatment (16.3 to 14.0%) that were reduced with the 85C heat treatment (9.9 to 12.2%). Salmon heads exhibited a higher percent soluble protein after the heat treatment than either pollock or cod heads ($P<0.05$). The percent soluble protein was reduced by 40%, 44% and 11% after the 85C heat treatment in pollock, cod, and salmon whole fish, respectively.

Viscera that were not heat treated exhibited the highest ($P<0.05$) percent soluble protein when compared to other by-product components within a species. There were substantial decreases in percent soluble protein after pollock and salmon viscera were heated to 85C ($P<0.05$); however, the cod viscera exhibited similar percent soluble protein values both before and after the 85C treatment. One major difficulty in working with viscera is control of the endogenous proteolytic activity. High concentrations of soluble proteins are present in visceral tissues; however, proteolysis (endogenous enzymes from the digestive system) before, during, and after fish processing may generate additional soluble proteins and peptides. To control the proteolytic activity, the viscera were collected immediately after removal from the fish at the processing plants, kept at 4C, ground, sampled and frozen in a -30C blast freezer. The

TABLE 3.
HEATING AND % PROTEIN SOLUBILITY OF BY-PRODUCT STREAM COMPONENTS[1]

	Species	Whole Fish	Heads	Viscera	Frames	Skin	Fillet	H&G
% Soluble Protein 30 C	Pollock	18.2^{Au}	16.3^{Au}	61.6^{Av}	15.3^{Au}	3.7^{Aw}	15.2^{Au}	ND
		3.3	1.4	4.7	0.2	1.6	0.8	
	Cod	23.0^{Bu}	14.0^{Aw}	36.0^{Bv}	14.1^{Aw}	5.1^{Ay}	10.2^{Bx}	ND
		1.3	1.1	0.3	0.3	2.1	2.8	
	Salmon	16.8^{Ax}	24.3^{By}	47.7^{Cz}	ND	ND	ND	11.2
		2.6	3.4	0.3				1.4
% Soluble Protein 85 C	Pollock	11.0^{Aux}	11.3^{Aux}	18.3^{Av}	9.9^{Auwx}	49.1^{Ay}	5.2^{Awx}	ND
		1.4	0.8	1.6	1.8	0.8	0.8	
	Cod	12.8^{Auw}	12.2^{Aw}	41.9^{Bv}	10.5^{Auw}	47.3^{Ay}	4.8^{Ax}	ND
		3.1	1.5	4.3	1.4	7.3	0.3	
	Salmon	15.0^{Ax}	18.3^{Bx}	33.8^{Cy}	ND	ND	ND	5.8
		1.1	2.8	2.7				3.0

[1] Values are means of three replications; standard deviations listed below.
ND is not determined.
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frozen samples were stored at -75C and then thawed rapidly and held at 4C for weighing. When fish tissues were homogenized in 30C water and incubated for 30 min prior to the centrifugation step there would be some opportunity for proteolytic degradation. However, in the fish tissues heated to 85C before the 30 min incubation, rapid degradation of proteolytic activity would be expected.

All samples of fish processing wastes that were heated to 85C had at least 10% soluble protein (heads, frames, viscera and skins). Within a species the waste stream components with the greatest percent soluble protein were skin and viscera ($P<0.05$). Viscera has both endogenous intact soluble proteins and also soluble protein fragments and peptides produced by proteolysis. For skin a large increase in soluble protein is due to increased connective tissue solubility at 85C. The connective tissue of other tissues such as heads and frames could be important contributors to the percent soluble protein values after heating to 85C (Table 4).

Connective Tissue Content

The hydroxyproline content of fish tissues are listed in Table 4. Within a species the highest hydroxyproline values were obtained for skin ($P<0.05$) and lowest values for fillet and viscera. The high content of hydroxyproline observed in the heads and frames is due in part to the connective tissue in skin and bone components of these samples. The connective tissue as a percent of total protein was calculated from the hydroxyproline content of the samples (Table 4). Percent connective tissue between species for a common by-product stream components were similar ($P>0.05$) in all cases except for viscera. Percent connective tissue content values for viscera ranged from 1% for pollock to 5% for cod ($P<0.05$). Connective tissue content as a percent of total protein for pollock (45.5%) and cod skins (42.6%) are in general agreement with collagen yields of 49.8 to 51.4% of dried weight for three different species of fish skin reported by Nagai and Suzuki (2000). Montero *et al.* (1990) reported yields of muscle connective tissue from hake (1.7%) and trout muscle (1.4%) similar to the 1.6% connective tissue content (as a percent of total protein) for both pollock and cod fillets listed in Table 4. Collagen is the most abundant single protein in vertebrates, is a major extracellular structural protein, contains lower concentrations of essential amino acids, and exhibits unique physical properties.

The estimated rat PER values presented in Table 4 were calculated from the method of Lee *et al.* (1978) for estimating the PER based on the connective tissue content in meat samples. Estimated rat PER values for pollock (2.11) and cod (2.18) skins were the lowest values ($P<0.05$) for by-product stream components within a species. These values are smaller than the 2.5 PER value for reference standard casein in the standardized rat bioassay. High PER values (3.09 to 3.13) were obtained for pollock and cod fillet and pollock and salmon

TABLE 4.
CONTENT OF HYDROXYPROLINE AND CONNECTIVE TISSUE AND PREDICTED PER VALUE[1]

	Species	Whole Fish	Heads	Viscera	Frames	Skin	Fillet	H&G
% Hydroxyproline	Pollock	0.85^{Au}	1.22^{Auw}	0.12^{Avx}	0.95^{Auw}	5.69^{Ay}	0.20^{Az}	ND
		0.13	0.24	0.04	0.12	0.60	0.05	
	Cod	0.72^{Au}	1.64^{Aw}	0.62^{Bu}	1.33^{Aw}	5.33^{Ax}	0.20^{Av}	ND
		0.07	0.34	0.14	0.10	0.18	0.05	
	Salmon	0.71^{Ax}	1.20^{Ay}	0.33^{Az}	ND	ND	ND	0.61
		0.23	0.13	0.08				0.32
% Connective Tissue	Pollock	6.82^{Au}	9.78^{Au}	0.97^{Av}	7.56^{Au}	45.50^{Aw}	1.59^{Ax}	ND
		1.07	1.92	0.28	0.92	4.81	0.36	
	Cod	5.73^{Au}	13.15^{Av}	4.99^{Bu}	10.64^{Av}	42.63^{Aw}	1.59^{Ax}	ND
		0.58	2.71	1.08	0.80	1.46	0.42	
	Salmon	5.66^{Ax}	9.63^{Ay}	2.65^{Ax}	ND	ND	ND	4.92
		1.80	1.03	0.66				2.52
Estimated Rat PER	Pollock	3.00^{Au}	2.93^{Au}	3.13^{Av}	2.98^{Au}	2.11^{Aw}	3.12^{Av}	ND
		0.02	0.04	0.01	0.02	0.11	0.01	
	Cod	3.02^{Au}	2.85^{Bv}	3.04^{Bu}	2.91^{Av}	2.18^{Aw}	3.12^{Ax}	ND
		0.01	0.06	0.03	0.02	0.03	0.01	
	Salmon	3.02^{Ax}	2.93^{Ay}	3.09^{ABz}	ND	ND	ND	3.04
		0.04	0.02	0.02				0.06

[1] Values are means of three replications; standard deviations are listed below. ND is not determined.

% hydroxyproline and % connective tissue are expressed as % of total protein. Estimated rat PER calculated by the method of Lee *et al.* 1978.

^{ABC} Superscripts with different letters within a column category are different ($P<0.05$).

^{uvwxyz} Superscripts with different letters within a row are different ($P<0.05$).

viscera. Onodenalore and Shahidi (1996) calculated shark muscle PER values to be 3.09 to 3.19 from amino acid composition data which are in general agreement with the calculated PER values of 3.12 for both pollock and cod fillets in this study. The fillet PER values compare favorably to the PER value of 3.06 obtained by Lee *et al.* (1978) for raw deboned chicken meat. Estimated PER values for fish frames, head and viscera ranged from 2.85 to 3.13 with small, but in some cases, significant differences between species. The estimated rat PER values calculated for pollock and cod frames and heads were similar ($P>0.05$) within species and ranged from 2.85 to 2.98. The PER values for different species of whole fish were similar ($P>0.05$) and ranged from 3.00 to 3.02, and values for viscera and fillet samples ranged from 3.04 to 3.13. This method has provided a useful calculation for estimating the rat PER value for fish processing waste stream components; however, feeding trials of selected by-products are planned in the future.

CONCLUSIONS

The major components of fish processing wastes from both Alaska pollock and Pacific cod filleting operations are heads, viscera, frames and skins. For pink salmon the two major waste components are heads and viscera. The compositions of waste stream components were analyzed. As a generality many properties of pollock and cod were similar; however, many salmon properties were different. There were significant compositional differences between heads, viscera and skin. Protein solubility is an important parameter in the processing of fish wastes (e.g. conversion of fish waste to fish meal) and in aquaculture feeds. Percent protein solubility was greatest for viscera before heating to 85C and the percent soluble protein in both pollock and cod skin was greatest after heating to 85C. The amount of connective tissue protein in an animal tissue is an important parameter affecting processing properties and nutritional value. Skin had the highest connective tissue content as a percent of total protein at approximately 45%, frames and heads had 7 to 13%, and viscera was 1 to 5%. Estimated rat PER values ranged from a low of 2.1 for skin to a high of 3.1 for viscera and fillets. The results from this study identify some of the important characteristics of individual fish by-product components that could be used to create new products and feed ingredients.

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