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Protein quality and amino acid profiles of fish products available in Poland

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ABSTRACT

Chemical analyses were carried out on 18 of the most popular varieties of fish products in the Polish market (canned, smoked, salted and marinated fish of different species), produced by the largest manufacturers and distributors in the country. The contents of the nutritive substances in the fish products (proteins, amino acids, and fats) were determined. To assess the nutritional quality of proteins in these products, the protein digestibility was determined, which ranged from 77.0% to 98.7%, and the amino acid composition of each of these groups of products was compared with that of a standard protein recommended by the World Health Organization (WHO). In addition, protein digestibility-corrected amino acid scores (PDCAAS) were calculated. Relative to the WHO protein standard, most of the fish products tested scored very high, with values ranging between 0.9 and 1.0. This study confirmed that in terms of both quantity and quality, fish products in the Polish market could serve as a significant source of essential amino acids and that the sulphur-containing essential amino acids and lysine present in fish products could supplement the corresponding deficiency in plant proteins. However, it was also indicated that drastic thermal processes, such as sterilisation, could influence the protein digestibility.

1. Introduction

The low consumption of fish and fish products in Poland as compared to that in other European countries (6.4 kg/per capita, including about 1.5 kg of canned fish) (Szostak, Kuzebski, & Budny, 2006) is due, amongst other reasons, to inadequate promotion and a lack of sufficient information regarding their nutritional qualities.

Fish is known to be a source of protein rich in essential amino acids (lysine, methionine, cystine, threonine, and tryptophan) (Sikorski, 1994), micro- and macroelements (calcium, phosphorus, fluorine, iodine), fats that are valuable sources of energy, fat-soluble vitamins, and unsaturated fatty acids that, amongst other benefits, have a hypocholesterolemic effect (antiarteriosclerosis) (Fernandez & Venkatrammann, 1993; Ismail, 2005).

The Testing Laboratory at the Sea Fisheries Institute undertook projects aimed at supplying comprehensive data regarding the nutrient and pollutant content of the fish products prevalent in the Polish market to arrive at a reliable assessment of the quality and safety of these products and to entice consumers to enrich their diet with fish products. The contents and roles of nutrients such as polyunsaturated fatty acids, micro- and macroelements, and fat-soluble vitamins, in addition to the contents of chosen pollutants, such as pesticides, polychlorinated biphenyls, polychlorinated dibenzo-*p*-dioxins and dibenzofurans, polybrominated diphenyl ethers, and metals were presented in previous papers (Usydus et al., 2008; Usydus et al., submitted for publication). In this report, data on the contents and quality of fish proteins, some of the most important nutrient components, are presented. To assess the nutritional quality of the protein in the products tested, the digestibility and composition of the protein were determined. The amino acid composition of each of these groups of products was compared with that of a standard protein recommended by the World Health Organization (FAO/WHO., 1991).

Amino acids play a central role as the building blocks of proteins and as intermediates in metabolism and further help to maintain health and vitality. There are 20 amino acids that can be found in the human body, 18 of which are important in human nutrition. Eight amino acids cannot be synthesised de novo by humans and other mammals and hence must be supplied in the diet; therefore they are called essential amino acids (Hryniewiecki, 2000). The essential amino acids are lysine, methionine, threonine, tryptophan, isoleucine, leucine, phenylalanine and valine. Failure to obtain enough of even one of the essential amino acids results in the degradation of the muscle proteins in the body. Moreover, there is a group of amino acids which are not normally required in the diet but which must be exogenously supplied to specific populations under special conditions, such as intensive growth, stress, or in some disease states. Such amino acids have been classified as semi-essential. This group includes histidine, serine and arginine. The remaining amino acids (alanine, cystine, glycine, aspartic acid, glutamic acid, proline and tyrosine) are synthesised by the organism in sufficient amounts and hence are classified as nonessential amino acids. In addition, cystine and

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tyrosine are regarded by some authors (Boisen, Hvelplund, & Weisbjerg, 2000) as semi-essential amino acids as they are synthesised from methionine and phenylalanine, respectively. Therefore, the total amino acid requirements should include the sum of methionine + cystine (sulphur-containing amino acids) and phenylalanine + tyrosine (aromatic amino acids). Fulfilling the requirements as above, equivalent to the summed quantities alone, may not be sufficient because methionine and phenylalanine cannot be synthesised from cystine and tyrosine, respectively (Boisen et al., 2000).

The nutritive quality of any food protein is determined by the following factors:

– the content of essential and nonessential amino acids;
– the mutual proportions of specific essential amino acids, which preferably – should be similar to that found in the proteins of the body;
– the energy supplied, which is essential for protein synthesis in the body;
– the digestibility of the protein (Hryniewiecki, 2000).

The quality of the proteins can be determined in relation to the composition of a standard protein, which is recognised as the most relevant for the assessment of the protein quality in the nutrition of all populations. The amino acid composition of a WHO standard protein has been modified by the Joint Expert Committee of the FAO in 1991 (FAO/WHO, 1991), with relevance to the present knowledge. The evaluation of protein quality is carried out on the basis of the amounts of limiting amino acids. These are the essential amino acids found in foodstuffs in the smallest quantities in comparison with a standard protein. The limiting amino acid content profoundly affects the net protein utilisation, which is the ratio of the mass of amino acids converted to proteins against that of amino acids supplied. Therefore foodstuffs that have different deficiencies in their essential amino acid profiles in comparison with a standard protein should be mixed for consumption. For example, the proteins of cereal products are characterised by a low content of lysine and hence should be supplemented with proteins rich in this amino acid so as to optimise the utilisation of the proteins supplied in the diet.

A cross-sectional consumer survey has been carried out in November–December 2004 in five European countries Belgium, Denmark, The Netherlands, Poland, and Spain, and subsequently, a representative sample for age and region, consisting of 4786 consumers within each country, has been obtained. The results show that fish has an overall "healthy image" amongst a very large majority of the population. Consumers perceive fish, regardless of the species, as a very healthy and nutritious food and consider eating fish as essential for a balanced and healthy diet (Pieniak, Verbeke, Brunsø, & Scholder, 2007). In conjunction with the above studies and other earlier related reports (Usydus et al., 2008; Usydus et al., submitted for publication), this study proposes to confirm the positive opinion and support it with comprehensive data.

2. Materials and methods

2.1. Samples and analysis

As many as 240 samples of canned, smoked, salted, and marinated fish were tested in 2005 and 2006. These were the most popular of the fish products in the Polish market. The samples were purchased from large supermarkets, grocery stores, or directly from the manufacturers. The following assortments of fish products were chosen for testing:

Canned fish	
Sprat in tomato sauce	10 samples
Sprat in oil	20 samples
Herring in tomato sauce	20 samples
Herring in oil	20 samples
Tuna in oil	10 samples
Mackerel in tomato sauce	10 samples
Mackerel in oil	10 samples
Sardine in oil	10 samples
Paprykarz (fish spread with rice)	10 samples
Smoked fish	
Smoked mackerel	10 samples
Smoked sprat	10 samples
Smoked herring	10 samples
Smoked Baltic salmon	10 samples
Smoked Norwegian salmon/farmed	10 samples
Smoked trout	10 samples
Salted fish	
Salted herring fillets	30 samples
Marinated fish	
Marinated herring fillets	20 samples
Fried mackerel in vinegar	10 samples

Mackerel, sprat, herring, and trout were hot-smoked whereas salmon was cold-smoked.

Each pooled sample comprised eight to 10 items (cans, pots, or barrier-flexible trays) from one lot or from 3 kg of unpacked products. In the case of canned fish, the samples consisted of the entire content in the cans. In the case of other fish products, the samples consisted of skinless fillets, with the exception of sprat samples that consisted of fillets with skin.

The determinations of the crude protein and fat, dry matter and ash, as well as the protein digestibility assays, were carried out at the Accredited Testing Laboratory of the Sea Fisheries Institute in Gdynia. The chemical compositions of all the samples were determined by the following AOAC (1990) procedures: dry matter, by drying in an oven at 103 °C for 8 h; crude fat, by Soxhlet extraction with ether; crude ash, by incineration in a muffle furnace at 580 °C for 8 h; crude protein (N ×6.25), by the Kjeldahl method after an acid digestion; nondigestible proteins, by Kjeldahl method after enzymatic hydrolysis of the digestible protein with pepsin; finally, digestible proteins were obtained as the difference between the crude and nondigestible proteins.

Amino acid determinations were carried out in the Central Laboratory of the National Research Institute of Animal Production in Krakow. Amino acids in the freeze-dried samples were analysed after acid hydrolysis in 6 N HCl for 22 h at 110 °C in glass tubes under nitrogen. Cystine and methionine were determined as cysteic acid and methionine sulphone, respectively, by performic acid oxidation before their digestion using 6 N HCl (Blackburn, 1968; Moore 1963,). Tryptophan was determined by the method of Landry, Delhaye, and Jones (1992), after alkaline hydrolysis of each sample. Chromatography analysis was carried out using the Beckman-System Gold-126 AA, equipped with an ion-exchange column and a UV–VIS detector; and postcolumn derivatization with ninhydrin was carried out. All analyses were conducted in duplicate for each sample. Quantification was obtained by using external standards, and the results were corrected for the recoveries.

Protein digestibility-corrected amino acid scores (PDCAAS) of the samples were calculated by multiplying the lowest amino acid ratio (mg of an essential amino acid in 1.0 g test protein/mg of the same amino acid in 1.0 g reference pattern for the eight essential amino acids plus tyrosine, cystine, and histidine) by the in vitro protein digestibility. The PDCAAS scores were expressed in percentage terms (El & Kavas, 1996).

2.2. Statistical analysis

Statistical analyses were conducted with the STAT statistical software package (Statistica, Version 8.0); *T*-tests with the estimation of variance (test Cohrana-Coxa) were applied to test for differences in the mean values of protein digestibility and amino acid content amongst the groups of products analysed; significance level $P < 0.05$ was used. Paprykarz was excluded from the statistical calculations because the protein digestibility and amino acid content for this canned product were apparently different from those of the other samples tested.

All the tables provided herein contain mean values ± standard deviation (SD).

3. Results and discussion

The compositions of the chosen fish products in the Polish market and their protein digestibilities are shown in Table 1. Crude protein (N× 6.25), total lipids, and ash content of the fish products tested were 6.71–23.34%, 5.38–36.26%, and 1.18–6.39%, respectively, on a wet-weight basis. The highest lipid content was observed for fish canned in oil (about 30%) due to the fact that samples consisted of the entire content in cans. Other products made from mackerel were also characterised by a relatively high lipid content (about 20%).

The lowest protein content was determined in the paprykarz (fish spread with rice), with a mean value of 6.71%. The most valuable products with regard to the protein content (above 20%) were smoked sprat, salmon and trout. The quality of the protein was evaluated by the determination of the protein digestibility. The least digestible protein (at 77%) was found in paprykarz, probably due to the presence of rice protein, known to be less digestible than animal proteins. The protein digestibility of the remaining samples varied between 90.6% and 98.7%. Thus, proteins in canned fish were characterised by a lower digestibility (between 90.6% and 95.4%) than those in smoked, marinated, and salted products that were not exposed to such drastic thermal processes (sterilisation) as canned products. In these products, the protein digestibility varied from 97.0% to 98.7%. The negative influence of thermal processing on the quality of proteins in fish was also indicated in other studies. It was suggested that protein digestibility could be reduced as a result of complex chemical reactions, such as protein–protein interactions, or protein–fat interactions taking place when food is treated at high temperatures (El & Kavas, 1996).

Statistical analysis confirmed that the protein digestibility of canned fish products was statistically significantly different from that in the other products analysed. No statistically significant differences were found between the digestibilities of proteins from smoked, salted, and marinated fish products.

To further investigate the quality of proteins in the tested samples, the amino acid composition was determined. The amino acid compositions of proteins in canned fish and other fish products are shown in Tables 2 and 3. When the results were expressed per 100 g of product, the sum of essential amino acids ranged between 2.24% in paprykarz to 9.70% in smoked trout. Comparing the results for fish canned in oil and tomato sauce, fish canned in oil were characterised by a greater content of essential amino acids (between 6.69% and 8.19%) than fish canned in tomato sauce (between 4.60% and 5.04%). The differences in the amino acid contents between fish products canned in oil and those in tomato sauce were statistically significant. Amongst the canned products, the largest amounts were observed for sardines in oil. Smoked products were characterised by greater contents of essential amino acids in comparison to other tested products. In this group of products, the content of essential amino acids varied from 7.66% to 9.70%, with the lowest results recorded for mackerel and the largest for trout. A relatively low content of essential amino acids was observed for the salted herring fillets. The essential amino acid requirement for an adult man weighing 70 kg is about 5.6 g per day (Gawędzki, 1997). The results indicated that 100 g of smoked and marinated fish products, as well as the fish products canned in oil, met the daily requirement for essential amino acids.

The predominant amino acids amongst the nonessential amino acids were aspartic acid and glutamic acid, and those amongst the essential amino acids were lysine and leucine. Tables 4 and 5 present the mutual proportion of the essential amino acids in a standard protein and in the samples tested, expressed as g/100 g protein. The amount of essential amino acids in all the analysed samples was greater than that in the standard protein (32 g/100 g protein) and varied from 33.4 to 48.4 g/100 g protein.

The amino acid profile of smoked Baltic salmon (as an example) was compared with that in a standard WHO protein (Fig. 1). As

Table 1
Chemical characteristics of the fish products in the Polish market

Varieties of products	Protein (g/100 g)[a]	Digestibility (%)[a]	Lipid (g/100 g)[a]	Ash (g/100 g)[a]	Dry matter (g/100 g)[a]
Canned sprat in tomato sauce (*n* = 10)	11.5 ± 0.74	9117 ± 4.0	5.38 ± 1.93	2.43 ± 0.35	23.7 ± 2.10
Canned sprat in oil (*n* = 20)	13.2 ± 1.08	93.0 ± 2.83	27.8 ± 3.82	2.3 ± 0.3	43.6 ± 4.67
Canned herring in tomato sauce (*n* = 20)	12.0 ± 1.34	90.6 ± 3.42	7.61 ± 3.26	2.02 ± 0.25	25.7 ± 3.68
Canned herring in oil (*n* = 20)	14.4 ± 1.77	95.4 ± 1.72	30.0 ± 7.81	1.73 ± 0.28	46.0 ± 6.8
Canned tuna in oil (*n* = 10)	15.7 ± 2.42	93.7 ± 3.05	27.2 ± 5.59	1.18±0.26	43.9 ± 6.52
Canned mackerel in tomato sauce (*n* = 10)	12.7 ± 0.88	92.2 ± 2.18	8.49 ± 3.39	1.84 ± 0.2	28.0 ± 3.44
Canned mackerel in oil (*n* = 10)	13.7 ± 1.69	93.5 ± 3.02	36.3 ± 6.99	1.41 ± 0.26	51.0 ± 5.93
Canned sardine in oil (*n* = 10)	16.7 ± 1.49	95.0 ± 1.43	27.3 ± 8.06	2.60 ± 0.75	46.4 ± 8.08
Fish spread and rice (*n* = 10)	6.71 ± 1.65	77.0 ± 13.2	6.55 ± 2.72	2.12 ± 0.26	25.5 ± 3.58
Smoked mackerel (*n* = 10)	19.7 ± 0.71	98.5 ± 0.28	20.8 ± 5.43	2.2 ± 0.61	42.4 ± 3.03
Smoked sprat (*n* = 10)	22.0 ± 2.29	97.7 ± 0.55	13.9 ± 2.35	4.33 ± 0.95	39.8 ± 3.2
Smoked herring (*n* = 10)	19.5 ± 0.79	98.1 ± 0.34	8.99 ± 2.38	3.16 ± 0.62	31.8 ± 2.19
Smoked Baltic salmon (*n* = 10)	22.3 ± 2.05	98.2 ± 0.8	11.5 ± 4.62	4.56 ± 0.94	38.8 ± 6.16
Smoked Norwegian salmon (*n* = 10)	19.7 ± 1.73	98.6 ± 0.3	15.5 ± 3.55	4.11 ± 0.7	39.8 ± 3.89
Smoked trout (*n* = 10)	23.3 ± 0.9	98.7 ± 0.25	6.06 ± 1.2	2.71 ± 0.96	31.7 ± 1.55
Salt herring fillets (*n* = 30)	12.8 ± 1.28	97.9 ± 0.41	14.4 ± 3.03	6.39 ± 1.38	33.9 ± 2.71
Marinated herring fillets (*n* = 20)	15.4 ± 1.97	97.8 ± 0.47	15.2 ± 4.44	2.28 ± 0.62	34.1 ± 3.6
Fried mackerel in vinegar (*n* = 10)	15.8 ± 1.33	97.0 ± 0.58	19.2 ± 5.65	1.89 ± 0.27	40.3 ± 4.66

[a] Mean value ± SD of "*n*" separate samples.

Table 2
Amino acid composition of canned fish proteins in the Polish market (g/100 g products)

	Recommended daily intake[f]		Canned fish in tomato sauce			Canned fish in oil					Fish spread with rice (n = 7)[e]
	mg/kg body weight	g/70 kg body weight	Sprat (n = 9)[e]	Herring (n = 15)[e]	Mackerel (n = 7)[e]	Sprat (n = 15)[e]	Herring (n = 15)[e]	Tuna (n = 7)[e]	Mackerel (n = 8)[e]	Sardine (n = 7)[e]	
Phe + Tyr[a]	12.1	0.85	0.80 ± 0.09	0.87 ± 0.08	0.82 ± 0.14	1.15 ± 0.18	1.35 ± 0.19	1.31 ± 0.27	1.28 ± 0.31	1.37 ± 0.22	0.41 ± 0.12
Isoleucine	15.7	1.10	0.50 ± 0.06	0.53 ± 0.05	0.50 ± 0.08	0.71 ± 0.13	0.83 ± 0.09	0.86 ± 0.17	0.81 ± 0.17	0.87 ± 0.10	0.23 ± 0.05
Leucine	9.5	0.67	0.84 ± 0.09	0.92 ± 0.08	0.86 ± 0.13	1.20 ± 0.20	1.44 ± 0.18	1.42 ± 0.29	1.37 ± 0.28	1.46 ± 0.22	0.41 ± 0.11
Lysine	9.4	0.66	0.89 ± 0.08	0.99 ± 0.09	0.93 ± 0.15	1.36 ± 0.23	1.66 ± 0.20	1.66 ± 0.30	1.52 ± 0.25	1.70 ± 0.24	0.37 ± 0.11
Met + Cys[b]	12.1	0.85	0.31 ± 0.10	0.39 ± 0.05	0.36 ± 0.06	0.45 ± 0.11	0.66 ± 0.11	0.67 ± 0.13	0.59 ± 0.13	0.64 ± 0.10	0.19 ± 0.12
Threonine	6.5	0.46	0.52 ± 0.05	0.55 ± 0.05	0.52 ± 0.09	0.73 ± 0.12	0.86 ± 0.10	0.85 ± 0.16	0.82 ± 0.17	0.86 ± 0.13	0.24 ± 0.08
Tryptophan	2.9	0.20	0.14 ± 0.01	0.16 ± 0.03	0.15 ± 0.03	0.24 ± 0.07	0.25 ± 0.04	0.28 ± 0.06	0.26 ± 0.05	0.26 ± 0.05	0.1 ± 0.03
Valine	11.4	0.80	0.59 ± 0.06	0.63 ± 0.05	0.6 ± 0.08	0.85 ± 0.14	1.0 ± 0.13	1.02 ± 0.19	0.95 ± 0.18	1.02 ± 0.15	0.29 ± 0.06
∑ *Essential*	*79.6*	*5.59*	*4.60 ± 0.43*	*5.04 ± 0.44*	*4.75 ± 0.74*	*6.69 ± 1.08*	*8.06 ± 0.98*	*8.06±1.55*	*7.59±1.56*	*8.19±1.19*	*2.24±0.48*
Alanine			0.66 ± 0.10	0.68 ± 0.06	0.59 ± 0.06	0.85 ± 0.15	0.91 ± 0.17	0.97 ± 0.24	0.85 ± 0.21	1.05 ± 0.15	0.32 ± 0.07
Arginine			0.64 ± 0.07	0.66 ± 0.07	0.69 ± 0.09	0.77 ± 0.13	0.94 ± 0.14	0.82 ± 0.22	0.9 ± 0.18	1.00 ± 0.16	0.33 ± 0.07
Glycine			0.55 ± 0.15	0.54 ± 0.03	0.59 ± 0.09	0.73 ± 0.11	0.73 ± 0.12	0.81 ± 0.15	0.79 ± 0.19	0.96 ± 0.21	0.32 ± 0.08
Histidine			0.30 ± 0.12	0.30 ± 0.04	0.42 ± 0.09	0.37 ± 0.08	0.36 ± 0.05	0.95 ± 0.21	0.46 ± 0.23	0.76 ± 0.28	0.14 ± 0.04
Asp. acid[c]			1.10 ± 0.13	1.19 ± 0.12	1.13 ± 0.10	1.35 ± 0.27	1.5 ± 0.27	1.53 ± 0.42	1.31 ± 0.32	1.74 ± 0.19	0.56 ± 0.14
Glu. acid[d]			1.66 ± 0.17	1.78 ± 0.17	1.72 ± 0.32	1.82 ± 0.35	2.04 ± 0.34	2.05 ± 0.48	1.87 ± 0.47	2.15 ± 0.39	0.94 ± 0.15
Proline			0.30 ± 0.04	0.42 ± 0.05	0.42 ± 0.08	0.45 ± 0.08	0.49 ± 0.08	0.55 ± 0.2	0.56 ± 0.17	0.6 ± 0.10	0.24 ± 0.04
Serine			0.49 ± 0.05	0.5 ± 0.05	0.49 ± 0.09	0.57 ± 0.10	0.65 ± 0.08	0.65 ± 0.18	0.61 ± 0.15	0.7 ± 0.11	0.25 ± 0.05

[a] Phenylalanine + Tyrosine.
[b] Methionine + Cysteine.
[c] Aspartic acid.
[d] Glutamic acid.
[e] Mean value ± SD of "n" separate samples.
[f] According to Gawędzki J – red. "Białka w żywności i żywieniu", Poznań (1997).

Table 3
Amino acid composition in the proteins of fish products in the Polish market (g/100 g products)

Amino acids	Recommended daily intake[F]		Smoked fish						Salted fish	Marinated fish	
	mg/kg body weight	g/70 kg body weight	Mackerel (n = 7)[E]	Sprat (n = 8)[E]	Herring (n = 7)[E]	Baltic salmon (n = 8)[E]	Norwegian salmon (n = 7)[E]	Trout (n = 8)[E]	Herring fillets (n = 23)[E]	Herring fillets (n = 15)[E]	Fried mackerel in vinegar (n = 7)[E]
Phe + Tyr[A]	12.1	0.85	1.33 ± 0.11	1.46 ± 0.11	1.36 ± 0.08	1.65 ± 0.24	1.45 ± 0.20	1.70 ± 0.10	0.94 ± 0.12	1.15 ± 0.23	1.22 ± 0.22
Isoleucine	15.7	1.10	0.75 ± 0.06	0.83 ± 0.06	0.82 ± 0.06	1.01 ± 0.12	0.85 ± 0.11	0.93 ± 0.10	0.58 ± 0.07	0.67 ± 0.15	0.72 ± 0.13
Leucine	9.5	0.67	1.40 ± 0.12	1.49 ± 0.12	1.47 ± 0.10	1.68 ± 0.23	1.5 ± 0.21	1.68 ± 0.12	1.01 ± 0.13	1.22 ± 0.27	1.26 ± 0.22
Lysine	9.4	0.66	1.57 ± 0.14^{a}	1.64 ± 0.17^{a}	1.68 ± 0.11^{a}	1.92 ± 0.28^{b}	1.70 ± 0.24^{b}	2.04 ± 0.10^{b}	1.14 ± 0.18	1.37 ± 0.34	1.35 ± 0.23
Met + Cys[B]	12.1	0.85	0.58 ± 0.06	0.68 ± 0.06	0.70 ± 0.06	0.61 ± 0.13	0.67 ± 0.09	0.89 ± 0.05	0.42 ± 0.05	0.54 ± 0.08	0.55 ± 0.08
Threonine	6.5	0.46	0.85 ± 0.07	0.90 ± 0.07	0.87 ± 0.07	1.05 ± 0.13	0.94 ± 0.11	1.04 ± 0.04	0.61 ± 0.07	0.74 ± 0.15	0.79 ± 0.13
Tryptophan	2.9	0.20	0.23 ± 0.01	0.19 ± 0.01	0.24 ± 0.01	0.29 ± 0.04	0.25 ± 0.03	0.27 ± 0.01	0.14 ± 0.02	0.16 ± 0.03	0.17 ± 0.03
Valine	11.4	0.80	0.96 ± 0.08	1.03 ± 0.08	1.00 ± 0.07	1.19 ± 0.16	1.04 ± 0.14	1.15 ± 0.06	0.66 ± 0.08	0.81 ± 0.16	0.85 ± 0.15
∑ *Essential*	*79.6*	*5.59*	*7.66 ± 0.63*^{a}	*8.20 ± 0.65*^{a}	*8.15 ± 0.54*^{a}	*9.41 ± 1.25*^{b}	*8.41 ± 1.12*^{b}	*9.70 ± 0.52*^{b}	*5.50 ± 0.71*	*6.62 ± 1.38*	*6.91 ± 1.17*
Alanine			1.04 ± 0.11	1.19 ± 0.1	1.15 ± 0.1	1.26 ± 0.12	1.05 ± 0.12	1.21 ± 0.11	0.74 ± 0.14	0.87 ± 0.12	0.89 ± 0.15
Arginine			1.12 ± 0.35	1.21 ± 0.12	1.18 ± 0.12	1.29 ± 0.13	1.11 ± 0.14	1.2 ± 0.11	0.73 ± 0.14	0.88 ± 0.17	0.97 ± 0.19
Glycine			0.84 ± 0.08	1.05 ± 0.08	0.95 ± 0.08	1.08 ± 0.11	0.93 ± 0.09	1.07 ± 0.05	0.56 ± 0.11	0.72 ± 0.11	0.85 ± 0.17
Histidine			0.71 ± 0.06	0.59 ± 0.08	0.49 ± 0.03	0.59 ± 0.06	0.5 ± 0.08	0.58 ± 0.06	0.32 ± 0.04	0.38 ± 0.07	0.52 ± 0.12
Asp. Acid[C]			1.67 ± 0.17	1.88 ± 0.15	1.9 ± 0.17	2.16 ± 0.22	1.87 ± 0.24	2.26 ± 0.12	1.2 ± 0.14	1.54 ± 0.19	1.54 ± 0.25
Glu. Acid[D]			2.35 ± 0.23	2.65 ± 0.19	2.64 ± 0.22	2.91 ± 0.3	2.47 ± 0.36	3.02 ± 0.15	1.62 ± 0.19	2.12 ± 0.31	2.29 ± 0.48
Proline			0.58 ± 0.08	0.79 ± 0.08	0.72 ± 0.05	0.75 ± 0.09	0.75 ± 0.13	0.79 ± 0.14	0.44 ± 0.18	0.53 ± 0.07	0.6 ± 0.17
Serine			0.72 ± 0.06	0.83 ± 0.07	0.82 ± 0.08	0.94 ± 0.09	0.83 ± 0.11	0.95 ± 0.04	0.53 ± 0.07	0.66 ± 0.09	0.74 ± 0.12

[A] Phenylalanine + Tyrosine.
[B] Methionine + Cysteine.
[C] Aspartic acid.
[D] Glutamic acid.
[E] Mean value ± SD of "n" separate samples. Mean values in the same horizontal row with different superscript letters are significantly different ($P < 0.05$).
[F] According to Gawędzki J – red. "Białka w żywności i żywieniu", Poznań (1997).

illustrated, these profiles are similar. The amount of the predominant essential amino acid, lysine, ranged from 5.51 g in paprykarz to 11.5 g in herring that was canned in oil. In all the tested products, with the exception of paprykarz, the amount of this amino acid was higher than that in a standard protein. The content of essential amino acids in the tested samples was comparable with that reported for Atlantic fishes (flatfish, rainbow trout, and salmon) (El & Kavas, 1996; Kim & Lall, 2000; Wilson & Cowey, 1985).

The differences in both the lysine content and the sum of essential amino acids, within the various groups of products studied, were analysed using the Cohrana-Coxa test. In the group of fish canned in tomato sauce, statistically significant differences were found only between sprat and herring. Statistically significant differences were found between sprat in oil and all the remaining assortments of fish canned in oil, and there were no statistically significant differences amongst herring, mackerel, sardines, and tuna canned in oil.

Statistical significance of the differences in lysine and sum of essential amino acids amongst assortments within the group of smoked fish are presented in Table 3. Salted and marinated fish did not differ from each other as regards the lysine content and sum of essential amino acids, but the contents of the same were statistically significantly lower in this group of samples in comparison with smoked products.

Table 4
Essential amino acid composition in the proteins of canned fish in the Polish market (g/100 g protein)

Amino acids	Standard FAO/WHO (1991)[d]	Canned fish in tomato sauce			Canned fish in oil					Fish spread with rice
		Sprat (*n* = 9)[c]	Herring (*n* = 15)[c]	Mackerel (*n* = 7)[c]	Sprat (*n* = 15)[c]	Herring (*n* = 15)[c]	Tuna (*n* = 7)[c]	Mackerel (*n* = 8)[c]	Sardine (*n* = 7)[c]	(*n* = 7)[c]
Phe + Tyr[a]	6.3	6.99 ± 0.82	7.29 ± 0.63	6.51 ± 1.13	8.70 ± 1.39	9.39 ± 1.30	8.35 ± 1.72	9.36 ± 2.30	8.21 ± 1.29	6.11 ± 1.79
Isoleucine	2.8	4.36 ± 0.52	4.39 ± 0.41	3.98 ± 0.63	5.41 ± 0.95	5.8 ± 0.65	5.49 ± 1.07	5.95 ± 1.26	5.17 ± 0.60	3.43 ± 0.75
Leucine	6.6	7.34 ± 0.76	7.68 ± 0.65	6.82 ± 1.05	9.12 ± 1.51	9.99 ± 1.26	9.08±1.87	10.0 ± 2.04	8.72 ± 1.30	6.11 ± 1.64
Lysine	5.8	7.72 ± 0.73	8.29 ± 0.72	7.33 ± 1.16	10.3 ± 1.74	11.5 ± 1.42	10.6 ± 1.95	11.1 ± 2.23	10.2 ± 1.44	5.51 ± 1.64
Met + Cys[b]	2.5	2.67 ± 0.88	3.26 ± 0.43	2.83 ± 0.44	3.42 ± 0.80	4.60 ± 0.76	4.30 ± 0.84	4.31±0.93	3.82 ± 0.82	2.83 ± 1.79
Threonine	3.4	4.52 ± 0.46	4.58 ± 0.40	4.12 ± 0.68	5.50 ± 0.88	6.01 ± 0.71	5.42 ± 1.04	5.99 ± 1.22	5.15 ± 0.79	3.58 ± 1.19
Tryptophan	1.1	1.26 ± 0.11	1.37 ± 0.21	1.22 ± 0.21	1.80 ± 0.56	1.76 ± 0.26	1.79 ± 0.36	1.93 ± 0.38	1.58 ± 0.27	1.49 ± 0.45
Valine	3.5	5.16 ± 0.56	5.29 ± 0.42	4.71 ± 0.66	6.42 ± 1.10	6.97 ± 0.91	6.49 ± 1.20	6.93 ± 1.29	6.11 ± 0.91	4.32 ± 0.89
∑ *Essential*	*32.0*	*40.0 ± 3.7*	*42.2 ± 3.6*	*37.5 ± 5.8*	*50.7 ± 8.2*	*56.1 ± 6.8*	*51.5 ± 9.9*	*55.6 ± 11.4*	*49.0 ± 7.1*	*33.4 ± 8.5*

[a] Phenylalanine + Tyrosine.
[b] Methionine + Cysteine.
[c] Mean value ± SD of "*n*" separate samples.
[d] According to Gawędzki J – red. "Białka w żywności i żywieniu", Poznań (1997).

Table 5
Essential amino acid composition in the proteins of fish products in the Polish market (g/100 g protein)

	Standard FAO/WHO (1991)[d]	Smoked fish						Salted fish	Marinated fish	
		Mackerel (*n* = 7)[c]	Sprat (*n* = 8)[c]	Herring (*n* = 7)[c]	Baltic salmon (*n* = 8)[c]	Norwegian salmon (*n* = 7)[c]	Trout (*n* = 8)[c]	Herring fillets (*n* = 23)[c]	Herring fillets (*n* = 15)[c]	Fried mackerel in vinegar (*n* = 7)[c]
Phe + Tyr[a]	6.3	6.08 ± 1.94	6.62 ± 0.50	6.99 ± 0.43	7.35 ± 1.05	7.36 ± 1.03	7.28 ± 0.42	7.35 ± 0.92	7.44 ± 1.47	7.76 ± 1.51
Isoleucine	2.8	3.43 ± 1.10	3.76 ± 0.29	4.18 ± 0.30	4.50 ± 0.54	4.32 ± 0.57	3.98 ± 0.47	4.55 ± 0.58	4.37 ± 0.94	4.57 ± 0.87
Leucine	6.6	6.39 ± 2.04	6.76 ± 0.54	7.55 ± 0.51	7.47 ± 01.04	7.60 ± 1.05	7.19 ± 0.52	7.85 ± 1.05	7.92 ± 1.72	7.98 ± 1.49
Lysine	5.8	7.18 ± 2.31	7.44 ± 0.76	8.62 ± 0.57	8.53 ± 1.25	8.64 ± 1.23	8.73 ± 0.43	8.89 ± 1.40	8.86 ± 2.22	8.55 ± 1.59
Met + Cys[b]	2.5	2.65 ± 0.86	3.11 ± 0.33	3.58 ± 0.30	2.72 ± 0.59	3.42 ± 0.45	3.82 ± 0.20	3.26 ± 0.43	3.47 ± 0.52	3.50 ± 0.57
Threonine	3.4	3.88 ± 1.24	4.07 ± 0.33	4.46 ± 0.33	4.68 ± 0.59	4.78 ± 0.57	4.45 ± 0.19	4.74 ± 0.54	4.81 ± 0.94	4.98 ± 0.86
Tryptophan	1.1	1.05 ± 0.33	0.86 ± 0.06	1.23 ± 0.06	1.28 ± 0.16	1.25 ± 0.15	1.17 ± 0.05	1.09 ± 0.16	1.04 ± 0.21	1.09 ± 0.23
Valine	3.5	4.37 ± 1.39	4.68 ± 0.36	5.15 ± 0.34	5.29 ± 0.71	5.29 ± 0.69	4.95 ± 0.26	5.18 ± 0.62	5.25 ± 1.03	5.39 ± 1.02
∑ *Essential*	*32.0*	*38.8 ± 3.0*	*37.3 ± 3.0*	*41.8 ± 2.8*	*41.8 ± 5.54*	*42.7 ± 5.7*	*41.6 ± 2.3*	*42.9 ± 5.6*	*43.2 ± 8.95*	*43.8 ± 8.0*

[a] Phenylalanine + Tyrosine.
[b] Methionine + Cysteine.
[c] Mean value ± SD of "*n*" separate samples.
[d] According to Gawędzki J – red. "Białka w żywności i żywieniu", Poznań (1997).

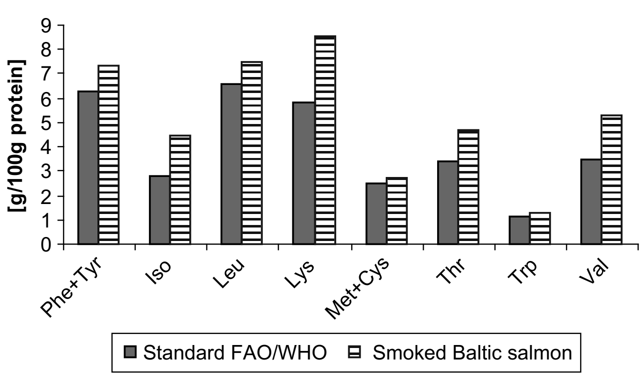

Fig. 1. Profiles of essential amino acids.

PDCAAS, on the basis of the amount of the most limiting amino acid, is suggested to be the most suitable method for assessing the protein quality of food with respect to the amino acid requirements of humans (El & Kavas, 1996). It measures the quality of a protein based on the amino acid requirements of a 2- to 5-year-old child (the most demanding age group), which is adjusted for digestibility. PDCAAS is thus based on the amino acid content of a food protein, its true digestibility, and its ability to supply indispensable amino acids in amounts adequate to meet the amino acid requirements of a 2- to 5-year-old child, the age group used as the standard. The highest PDCAAS value that any protein can achieve is 1.0. This score means that, after digestion of the food protein, one unit of protein provides 100% or more of the indispensable amino acids required by the 2- to 5-year-old child. A score above 1.0 is rounded down to 1.0.

The scores for the proteins in the fish products tested in the current studies ranged between 0.76 for smoked sprat to 1.0 for the majority of products. However, there are opposing opinions claiming that the truncation of PDCAAS values to 100% is justifiable only in those situations in which the protein is used as the sole source of energy in the diet and that, for the evaluation of the nutritional significance of proteins as part of a mixed diet, the truncated value should not be used (Schaafsma, 2000). Moreover, the limiting amino acid, singly, does not reflect the nutritional value of the protein in a mixed diet, because there are examples wherein the constituents of one protein can be complemented by those of another. For example, grain protein has a PDCAAS of about 0.4–0.5, limited by lysine. On the contrary, it contains more than sufficient methionine amounts. White-bean protein has a PDCAAS of 0.6–0.7, limited by methionine, and contains more than enough amounts of lysine. When both are eaten in approximately equal quantities in a diet, the PDCAAS of the combined constituent is 1.0, because the deficient amino acid in each constituent's protein is complemented by that in the other (Dutch Dairy Foundation on Nutrition and Health,1995).

Therefore, for the best representation of the characteristics regarding the protein quality of the tested products, the PDCAAS scores are not rounded to 100% in Tables 6 and 7. Moreover, these tables contain data, not only regarding the limiting amino acids, but also for all the 10 essential amino acids and histidine.

Table 6
PDCAAS score for canned fish proteins (%)

	Standard FAO/WHO (1991)[c] (g/100 g protein)	Canned fish in tomato sauce			Canned fish in oil					Fish spread with rice (*n* = 7)
		Sprat (*n* = 9)	Herring (*n* = 15)	Mackerel (*n* = 7)	Sprat (*n* = 15)	Herring (*n* = 15)	Tuna (*n* = 7)	Mackarel (*n* = 8)	Sardine (*n* = 7)	
Digestibility (%)		91.1	90.6	92.2	93.0	95.4	93.7	93.5	95.0	77.0
Phe + Tyr[a]	6.3	101	**105**	**95.2**	128	142	**124**	**139**	**124**	74.7
Isoleucine	2.8	142	142	131	180	198	184	199	175	94.3
Leucine	6.6	101	105	**95.2**	129	144	129	142	125	71.3
Lysine	5.8	121	130	117	166	190	172	179	167	73.2
Met + Cys[b]	2.5	**97.3**	118	104	127	176	161	161	145	87.2
Threonine	3.4	121	122	112	150	169	149	165	144	81.1
Tryptophan	1.1	104	113	102	152	153	153	164	136	104
Valine	3.5	134	137	124	171	190	174	185	166	95.0
Histidine	1.9	126	120	161	137	126	300	166	227	84.6

PDCAAS score of canned fish in relation to standard protein are typed bold fonts.
[a] Phenylalanine + Tyrosine.
[b] Methionine + Cysteine.
[c] According to Gawędzki J – red. "Białka w żywności i żywieniu", Poznań (1997).

Table 7
PDCAAS score for fish products proteins [%]

	Standard FAO/WHO (1991)[c] (g/100 g protein)	Smoked fish						Salted fish	Marinated fish	
		Mackerel (*n* = 7)	Sprat (*n* = 8)	Herring (*n* = 7)	Baltic salmon (*n* = 8)	Norwegian salmon (*n* = 7)	Trout (*n* = 8)	Herring fillets (*n* = 23)	Herring fillets (*n* = 15)	Fried mackerel in vinegar (*n* = 7)
Digestibility (%)		98.5	97.7	98.1	98.2	98.6	98.7	97.9	97.8	97.0
Phe + Tyr[a]	6.3	95.1	103	**109**	115	115	114	114	116	119
Isoleucine	2.8	121	131	147	158	152	140	159	153	158
Leucine	6.6	95.3	100	112	111	114	108	116	117	118
Lysine	5.8	122	125	146	144	147	149	150	149	143
Met + Cys[b]	2.5	104	122	141	**107**	135	151	127	136	136
Threonine	3.4	112	117	129	135	139	129	136	138	142
Tryptophan	1.1	**94.0**	**76.3**	110	114	**112**	**105**	**97.0**	**92.5**	**96.1**
Valine	3.5	123	131	143	148	149	140	145	147	149
Histidine	1.9	187	138	130	137	132	129	129	127	168

PDCAAS score of fish products in relation to standard protein are typed in bold fonts.
[a] Phenylalanine + Tyrosine.
[b] Methionine + Cysteine.
[c] According to Gawędzki J – red. "Białka w żywności i żywieniu", Poznań (1997).

Summarizing the results of this study, fish products in the Polish market can be concluded to serve as significant sources of essential amino acids, in terms of both quantity and quality. In some products, the composition of essential amino acids was even more advantageous than that in the standard egg protein (Hryniewiecki, 2000). Limiting amino acids in the diet, such as lysine, methionine and cystine, expressed as g per 100 g of protein, occurred at levels similar to or even greater than those in the standard protein (FAO, 1991).

These fish products are particularly good sources of lysine, which is severely restricted in cereals, the most important staple food in the world. A reduced supply of lysine in the diet may lead to mental and physical handicaps because it is an important precursor for the de novo synthesis of glutamate, the most significant neurotransmitter in the mammalian central nervous system (Papes, Surpili, Langone, Trigo, & Arruda, 2001). Furthermore, the sulphur-containing essential amino acids in fish products can supplement the corresponding deficiency in plant proteins. Thus, the proteins in a mixed diet can be utilised optimally for a healthy body constitution.

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