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Marine and farmed fish in the Polish market: Comparison of the nutritional value

Zygmunt Usydus *, Joanna Szlinder-Richert, Maria Adamczyk, Urszula Szatkowska

Sea Fisheries Institute in Gdynia, Department of Food and Environment Chemistry, 1 Kołłataja Street, 81-332 Gdynia, Poland

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ABSTRACT

The proximate composition and fatty acids profiles of the muscle tissues of nine fish species that are popular on the Polish market were examined. The nine studied fish species were: Baltic fish (cod, herring, salmon), fish farmed in Poland (carp, trout), oceanic fish imported from China (walleye pollock, sole), and farmed fish imported from Vietnam and China (sutchi catfish, tilapia). The lowest lipid content (below 0.1%) was noted in the muscle tissues of Baltic cod and walleye pollock caught in the Pacific. The muscle tissue of walleye pollock also had the lowest protein content (12.2 ± 2.0%). The highest lipid content was noted in the muscle tissues of Baltic salmon (13.1 ± 2.4%). The highest percentage content of eicosapentaenoic (C20:5 $n-3$ – EPA) and docosahexaenoic (C22:6 $n-3$ – DHA) acids (over 40%) was noted in the fat extracted from the oceanic fish and Baltic cod. However, due to the low fat content, the concentrations of EPA + DHA in these fish species and in imported farmed fish expressed in mg/100 g of muscle tissues are the lowest and range on average from 24.8 ± 5.7 mg/100 g (sutchi catfish) to 207.4 ± 125.4 mg/100 g (sole). This is why the consumption of these fish species has no significant meaning for coronary heart disease prevention. Consumers with symptoms of cardiovascular diseases should include the following fish species, which have high concentrations of EPA + DHA: Baltic salmon (3807.2 ± 666.3 mg/100 g); Polish farmed trout (1804.0 ± 279.2 mg/100 g); and Baltic herring (940.9 ± 306.6 mg/100 g) in their diets. However, the consumption of Baltic salmon must be limited on account of the levels of persistent organic pollutants found in it.

1. Introduction

The nutritional properties of fish and fish products render them valuable foodstuffs that are beneficial for human health. In comparison to other European countries, the per capita consumption of fish and fish products in Poland is low (11.7 kg live weight/per capita) (Szostak, Kuzebski, & Budny, 2007). This stems from poor marketing and a lack of adequate information for consumers regarding the nutritional values of these foodstuffs.

The nutritional benefits of fish stem for the most part, from its exceptionally advantageous fatty acids profile. In recent years, increasing attention has been focused on the significance of polyunsaturated fatty acids (PUFAs) in human nutrition, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). These long-chain, polyunsaturated fatty acids (LC-PUFAs; acids comprising 20 or more carbon atoms and at least three double bonds) are the major components of cellular membranes (Graham, Larson, & Napier, 2007). LC-PUFAs play important roles in regulating biochemical and physiological processes. For these reasons LC-PUFAs are numbered among those food ingredients with beneficial human health properties (Pond, 1998).

LC-PUFAs can be classed according to the position of the first double bond in the $n-3$ and $n-6$ family. EPA and DHA belong to the $n-3$ family of fatty acids. Specific interest in $n-3$ acids began to grow after researchers observed that the Inuit people from Greenland rarely suffered from cardiovascular diseases (CVD). The Inuit diet contained mainly fat fish and sea animals which have, among other qualities, high levels of EPA and DHA (Connor, 2000). The data obtained in epidemiological and experimental studies supported the beneficial activity of $n-3$ acids in the prevention of CVDs. In 2002, the American Heart Association (AHA) issued a declaration approving the use of $n-3$ acids in both the primary and secondary prevention of CVDs (Kris-Etherton, Harris, & Appel, 2002). EPA and DHA display several properties advantageous for human health. In addition to reducing the risk of some cardiovascular diseases (Calo et al., 2005; Ness et al., 2002; Rice, 2004) and cancers (Norat et al., 2005; Wolk, Larsson, Johansson, & Ekman, 2006), they can improve various functions in the human organism (Badalamenti, Salerno, & Lorenzano, 1995; Berbert, Kondo, Almendra, Matsuo, & Dichi, 2005).

Fish lipids are practically the only source of EPA and DHA. However, according to many scientists (Leskanich & Noble, 1997; Simopoulos, 2002), the prophylactic effects of fatty acids also depends on the ratio of the acids from the $n-3$ and $n-6$ families, which should be 1:5 (Sargent, 1997). The proportion of these fatty

* Corresponding author. Tel.: +48 0 58 7356162; fax: +48 0 58 7356110.
E-mail address: zygmunt@mir.gdynia.pl (Z. Usydus).

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acids in the diets of the average North American or Western European is much higher (approximately 1:20) due to the consumption of large quantities of vegetable oils and animal fats (Block & Pearson, 2006). The eight most commonly consumed fish species in the European Union are: rainbow trout, salmon, tuna, herring, mackerel, pilchard, anchovy and carp. According to the EFSA Journal (2005), the ratio of $n-3$ to $n-6$ in these species ranges from 20:1 (herring) to 3:1 (carp). Thus, if fish consumption is increased, the intake of $n-3$ acids in the overall diet will also increase.

Recently, many new fish species have appeared in the Polish, European, and North American markets. These new species include farmed fish originating from Vietnam and China, species caught in tropical and temperate oceanic regions (Yeh & Liu, 1983), and fish from African rivers and lakes (Getabu, Tumwebaze, & Mac Lennan, 2003; Tucker, 2003). These species are of growing interest to both the processing industry and consumers because of their technological suitability and palatable qualities. However, currently available data regarding nutritional qualities or the degree of contamination of these species are not sufficient to make a comprehensive evaluation of their nutritional significance. The least amount of information is available about the fish farmed in Vietnam and China.

Polish fish imports have been growing steadily since 2003, and 352,000 tons of fish and fish products were imported in 2006 (Szostak et al., 2007). The main species imported from Vietnam and China in 2006 were walleye pollock, sutchi catfish, and tilapia. These species comprised more than 25% of the fish imported in 2006, and, at 93,000 tons, this was four times higher than the 2005 imports.

The current paper presents the fatty acid composition and other nutritional values of fish species popular in the Polish market in order to compare the benefits they offer for consumer health. The studied fish were species originating from the Baltic Sea, fish farming in Poland, and both farmed and wild caught imported fish.

2. Materials and methods

2.1. Study material

The moisture, lipid content, protein, ash, protein digestibility, and fatty acid composition in the muscle tissues of nine fish species were examined. The species were as follows:

a. Baltic fish caught in the Polish catch area:
   - cod (*Gadus* morhua callarias);
   - herring (*Clupea* harengus membras);
   - Baltic salmon (*Salmo salar*);
b. fish farmed in Poland:
   - carp (*Cyprinus carpio*);
   - trout (*Oncorhynchus mykiss*);
c. oceanic fish imported from China:
   - walleye pollock (*Theragra chalcogramma*) from fishing areas FAO 61 and FAO 67, the Pacific;
   - sole (*Limanda aspera*) from fishing area FAO 67, the Pacific;
d. Farmed fish imported from Vietnam and China:
   - sutchi catfish (*Pangasius hypophthalmus*) farmed in Vietnam;
   - tilapia (*Oreochromis niloticus*) farmed in China.

Ten batches of fish from each of the species, which constituted separate samples, were collected and analysed. The Baltic fish were obtained in 2008 and 2009 during scheduled cruises of the r/v *Baltica* (cod and herring) or from fishing cutters (salmon) operating in the Polish Catch Area. The imported fish, which were frozen, skinned fillets in 0.5 kg packages, were purchased at supermarkets throughout 2009. Sampling was carried out in such a way that each sample was characterised by a different date of production. Fish farmed in Poland were purchased fresh from either supermarkets or directly from the fish farms.

The fish caught during the cruises of the r/v *Baltica* (cod, herring) were hermetically sealed and then stored in the ship's freezer at a temperature of −18 °C.

2.2. Sample preparation

The frozen fish (cod, herring, imported fish) was defrosted for 16 h at a temperature of 2–4 °C in a refrigerator. The liquid released during defrosting was discarded in order to analyse the fillet in the form it is consumed. Subsequently the whole fish or fillets were dried off with a paper towel. The defrosted (cod, herring) and fresh fish were filleted and skinned. These fillets and the fillets of imported fish were homogenised in a mixer (Multi Processor, Zelmer) for about 60 s at 1300 rpm. Each sample comprised of about 1 kg of fish muscle tissue. The fish samples used to determine the fatty acid composition were freeze-dried in an Alpha 2–4 LSC freeze dryer manufactured by Christ, GmbH.

2.3. Analytical methods

The determinations of the crude protein and fat, moisture, and ash, as well as the protein digestibility assays were carried out at the Laboratory of the Sea Fisheries Institute in Gdynia. The chemical compositions of all the samples were determined using the following AOAC (1990) procedures: moisture (%) – samples were dried in an oven at 103 °C for 8 h; crude fat (%) was determined gravimetrically after the Soxhlet extraction with petroleum ether; crude ash (%) by incineration in a muffle furnace at 580 °C for 8 h; crude protein ($N \times 6.25$) (%) by the Kjeldahl method after acid digestion; non-digestible proteins with the Kjeldahl method after enzymatic hydrolysis of the digestible protein with pepsin; digestible proteins (%) were obtained as the difference between the crude and non-digestible proteins. The percentage contents of moisture, protein, fat, and ash were determined in relation to the wet weight of the fish muscle tissues analysed.

The energy values were calculated using the mean values of protein and lipids in the fish muscle tissues analysed. The calculations were made with the following energy equivalents (Kunachowicz, Gawedzki, and Zielke, 2000):

- protein – 17 kJ/g
- lipids – 37 kJ/g

Fatty acids were determined for the total lipid fraction; 5–15 g of freeze-dried samples were extracted with 80 ml of a hexane: acetone mixture (4:1 v/v) in a Soxtec Avanti apparatus for 4 h. The solvents were evaporated carefully in a rotary evaporator under reduced pressure and a stream of nitrogen. The chromatographic analysis of the fatty acids was performed after they had been passed through the appropriate methyl esters (FAMEs) (EN ISO standard 5509:2000). An amount of 0.1 g of the extracted lipid was dissolved in 1.6 ml of 2 M methanolic potassium hydroxide solution and shaken vigorously. The solution was heated for 15 min in a heating block, and then cooled to room temperature. Subsequently, 3.2 ml of 4% methanolic solution of hydrochloric acid was added. The samples were reheated in the heating block for 15 min and then cooled to room temperature. An aliquot of 1.6 ml of isooctane was added and the solution was vortexed and adjusted to a volume of 10 ml with a saturated solution of sodium chloride. Anhydrous sodium sulphate was added to the dry extracts. The resultant solution of FAME on the top layer was diluted with methanol in a proportion of 1:4 v/v and was subjected

to the final determination (EN ISO standard 5509:2000). Extracts were analysed with an Agilent 6890 N GC gas chromatograph equipped with a flame-ionisation detector (FID). The column used was a Supelco SP 2560 (100 m length × 0.25 mm i.d.). Chromatography conditions were: split injection; split ratio – 100:1; injection volume – 2 μl; carrier gas flowing at 1.1 ml/min – helium; injection port temperature – 250 °C; detector temperature – 260 °C; oven temperature – initial oven temperature 140 °C held for 2 min, then increased to 225 °C at a rate of 2 °C/min and held for 10 min, followed by an increase to 240 °C at a rate 40 °C min^{-1} and held for 10 min. Identification and quantification were performed based on retention times and areas of peaks in the standard mixture (37 FAME Mix, C18:4 $n-3$, Supelco and C22:5 $n-3$, Supelco), using Agilent Technologies software (Chemstation; Rev A 10.02 [1757]). The content of components was expressed as percentages by the mass of the methyl esters (P_{fa}) and as concentration expressed in mg/100 g muscle tissue (C_{fa}). Correction factors (K_i) were used to convert the percentages of peak areas into mass percentages of the components. K_i were determined with a chromatogram derived from the analysis of a standard mixture carried out under operating conditions identical to those used for the samples according to the following formula (EU, 1991):

$$K_i = m_i \times \sum A(A_i \times \sum m)^{-1}$$

where: m_i is the mass of component i in the standard mixture; $\sum m$ is the total of the masses of the various components of the standard mixture; A_i is the area under the peak corresponding to component i; $\sum A$ is the sum of the areas under all the peaks.

The content of fatty acids C_{fa} expressed in mg/100 g muscle tissue was calculated using a conversion factor of 0.956 (Mèndez, Gonzàlez, Inocente, Giudice, & Grompone, 1996; Vasilopoulou et al., 2003) and the total lipid content (F_c) of muscle tissue according to the following formula:

$$C_{fai} = P_{fai} \times 1000 \times F_c \times 0.956 \times 10^{-2}$$

Certified reference material NIST 8415 (whole egg powder) was used to validate the method. The laboratory participated in intercalibration trials organised by FAPAS (FAPAS 1450), and achieved positive results (the z-scores for SFAs, MUFAs, and PUFAs were 0.8, 0.0, and 0.3, respectively).

2.4. Statistical analysis

The results of the analyses are presented as means ± standard deviation. Each result presented in the tables is the mean derived from the analyses of 10 samples collected in different periods from a given species.

Statistical analyses were conducted with the STAT statistical software package (Statistica, Version 8.0). The concentrations analysed were log-transformed and a significance level of $P < 0.05$ was used. Analysis of variance (ANOVA, Scheffe test) was used to verify whether there were differences in the protein content and SFA and MUFA concentrations among the analysed species. The homogeneity of variances was examined using Levene's test. With variables for which no homogeneity of variance was noted (fat content, PUFA concentrations, EPA + DHA concentrations), the significance of differences between chosen pairs of species were tested with the t-test with an independent estimation of variance (Cohrane–Cox test).

3. Results and discussion

3.1. Proximate composition

The proximate composition determined in nine fish species is shown in Table 1. The lowest lipid content (mean below 0.1%) was noted in the muscle tissues of Baltic cod and walleye pollock caught in the Pacific (Table 1). Relatively low lipid content (mean 0.5 ± 0.3%) was also observed in the muscle tissue of sole from the Pacific. A slightly higher lipid content was measured in the muscle tissues of imported farmed fish (1.3 ± 0.3% – sutchi catfish from Vietnam; 2.0 ± 0.6% – tilapia from China). These data are in agreement with the results obtained by other authors for tilapia (1.8%) (Puwastien et al., 1999) and sutchi catfish farmed in Vietnam (1.84 ± 0.92%) (Orban et al., 2008).

Among the fish analysed in this study the highest lipid content was noted in the muscle tissue of Baltic salmon (13.1 ± 2.4%). Similar results for Baltic salmon (12.6 ± 7.5%) were presented by Hansson, Persson, Larson, and von Schantz (2009) The same authors have measured significantly lower lipid content (4.3 ± 3.3%) in Atlantic salmon caught at the mouth of Mörrum river in Sweden. The Baltic herring caught in the Polish Catch Area (southern Baltic) was characterised by low lipid levels (3.7 ± 1.4%) in comparison to those of herring from the North Sea. As reported by Aidos, van der Padt, Luten, & Boom, 2002, the lipid content of herring from the North Sea ranges from 6% to 19%, depending on the season. The lipid content of Norwegian herring (*Clupea harengus* L.) is also higher and ranges from 7.2% to 17.5%, depending on the season (Hamre, Lie, & Sandnes, 2003). Among the fish farmed in Poland, higher lipid levels were noted in trout (7.4 ± 1.6%) than in carp (5.1 ± 3.0%), and these differences were statistically significant.

Table 1 shows the lower protein content in the muscle tissues of imported fish compared to fish from the Baltic or fish farmed in Poland. Among the fish species analysed, the lowest protein content was noted in the muscle tissues of walleye pollock (12.2 ± 2.0%), while the highest was measured in farmed trout (18.9 ± 0.8%) and Baltic salmon (18.4 ± 0.7%). Sutchi catfish from Vietnam, which recently has become very popular on the Polish market, also had low levels of protein (12.9 ± 0.8%). Orban et al. (2008) reported similar protein content results (13.6 ± 1.34%) from a study of sutchi catfish bought on the Italian market.

3.2. Percentage share of fatty acids

The percentage share of fatty acids in the extracted lipids is presented in Table 2. The lipids of farmed fish were characterised by a relatively high share of saturated fatty acids (SFAs). The highest level of these acids was noted in the lipids extracted from sutchi catfish (42.2 ± 2.0%), and the main constituent of this group was palmitic acid C16:0 (27.1 ± 1.0% in relation to the overall content of fatty acids). Similar results for sutchi catfish from the Italian market were reported by Orban et al. (2008) (SFAs content – 41.1–47.8%, C16:0 – 27.5–28.8%).

The percentage content of monounsaturated fatty acids (MUFAs) in the lipids of the species analysed varied over a wide range. The highest level of this group of fatty acids were noted in carp (51.1 ± 5.3%), and the lowest in cod and walleye pollock (8.5 ± 2.1% and 8.5 ± 4.6%, respectively). In all the species tested, the dominant acid of the MUFAs fraction was oleic acid (C18:$n-9$c), the percentage content of which, in relation to all the other fatty acids, fluctuated from 5.2 ± 3.9% (walleye pollock) to 39.5 ± 6.4% (carp). A high share of this acid was also noted in sutchi catfish (38.2 ± 1.1%), in which it comprised over 90% of all MUFAs. Orban et al. (2008) obtained similar results for this same species from the Italian market.

Typically, the highest percentage share of PUFAs was noted in the lipids of the leanest wild fish, (walleye pollock – 70.7 ± 6.8%; Baltic cod – 67.4 ± 4.4%; sole – 59.2 ± 4.6%). In the lipids of walleye pollock, cod, and sole analysed in the current study, the main acids of the PUFAs fraction were EPA and DHA, the shares of which in the total pool of the acids identified were 65.1 ± 2.5%, 58.4 ± 5.3%, and 43.4 ± 6.1%, respectively. The lowest percentage of PUFAs was typically noted in farmed fish reared in fresh water (sutchi catfish

Table 1
Mean proximate composition and protein digestibility of selected fish species available on the Polish market (mean value ± SD).

Component%	Cod	Herring	Baltic salmon	Carp	Trout	Walleye pollock	Sole	Sutchi catfish	Tilapia
Lipid	0.08 ± 0.02^{g}	3.7 ± 1.4^{c}	13.1 ± 2.4^{a}	5.1 ± 3.0^{c}	7.4 ± 1.6^{b}	0.09 ± 0.03^{g}	0.5 ± 0.3^{f}	1.3 ± 0.3^{e}	2.0 ± 0.6^{d}
Protein	17.4 ± 0.9^{b}	18.1 ± 0.5^{ab}	18.4 ± 0.7^{ab}	16.7 ± 0.8^{c}	18.9 ± 0.8^{a}	12.2 ± 2.0^{d}	13.4 ± 1.3^{d}	12.9 ± 0.8^{d}	16.4 ± 0.6^{c}
Moisture	81.5 ± 1.0	76.7 ± 1.5	67.3 ± 2.4	77.7 ± 2.6	73.0 ± 1.5	86.7 ± 1.9	85.0 ± 1.6	84.7 ± 0.3	81.2 ± 1.0
Ash	1.1 ± 0.2	1.4 ± 0.5	1.2 ± 0.2	0.6 ± 0.3	0.8 ± 0.2	1.0 ± 0.3	1.1 ± 0.3	1.1 ± 0.3	0.5 ± 0.2
Digestibility	98.5 ± 0.2	98.4 ± 0.4	98.4 ± 1.2	98.6 ± 0.4	98.4 ± 0.5	97.5 ± 0.3	97.9 ± 0.4	98.2 ± 0.3	98.4 ± 0.3

Latin names fish species analysed – cod (*Gadus morhua callaries*); herring (*Clupea harengus membras*); Baltic salmon (*Salmo salar*); carp (*Cyprinus carpio*); trout (*Oncorhynchus mykiss*); walleye pollock (*Theragra chalcogramma*); sole (*Limanda aspera)* sutchi catfish (*Pangasius hypophthalmus)* tilapia *(Oreochromis niloticus),*
The superscript notations ^{a,b,c,d,e,f,g} denote significant differences ($p < 0.05$) among all the fish species.

Table 2
Fatty acid composition (%) of the lipids extracted from selected fish species available on the Polish market (mean value ± SD).

Fatty acids%	Cod	Herring	Baltic salmon	Carp	Trout	Walleye pollock	Sole	Sutchi catfish	Tilapia
C12:0	ND	ND	ND	ND	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.6 ± 0.5	0.2 ± 0.2
C14:0	1.9 ± 0.4	6.2 ± 0.7	3.1 ± 0.3	1.3 ± 0.3	4.3 ± 0.5	1.8 ± 0.3	3.2 ± 1.0	4.4 ± 0.5	3.0 ± 0.3
C15:0	0.4 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.5 ± 0.1	0.3 ± 0.0	0.2 ± 0.0	0.6 ± 0.1	0.2 ± 0.0	0.4 ± 0.2
C16:0	17.7 ± 2.5	19.4 ± 0.6	16.8 ± 1.0	19.0 ± 1.1	13.4 ± 0.6	15.3 ± 1.5	15.8 ± 1.7	27.1 ± 1.0	24.7 ± 1.1
C17:0	0.2 ± 0.1	0.2 ± 0.1	0.5 ± 0.1	0.2 ± 0.1	0.1 ± 0.0	0.1 ± 0.0	0.2 ± 0.1	0.6 ± 0.1	0.4 ± 0.2
C18:0	3.5 ± 0.5	2.4 ± 0.4	3.3 ± 0.3	5.8 ± 0.9	3.6 ± 0.2	3.0 ± 0.8	3.9 ± 0.5	8.5 ± 0.6	6.0 ± 0.6
C20:0	0.2 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0.1 ± 0.0	0.2 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.2 ± 0.1	0.3 ± 0.0
C21:0	ND	ND	ND	ND	ND	ND	ND	0.2 ± 0.1	0.1 ± 0.0
C22:0	0.2 ± 0.0	ND	0.1 ± 0.1	0.1 ± 0.0	0.1 ± 0.0	ND	0.1 ± 0.0	0.3 ± 0.1	0.2 ± 0.0
C23:0	ND	ND	ND	ND	ND	ND	ND	ND	ND
C24:0	ND	ND	ND	ND	ND	0.2 ± 0.1	0.4 ± 0.2	0.1 ± 0.1	0.1 ± 0.0
∑SFA	**24.1** ± 2.9	**28.6** ± 1.0	**24.3** ± 0.9	**27.0** ± 1.6	**22.1** ± 1.0	**20.8** ± 2.5	**24.4** ± 1.9	**42.2** ± 2.0	**35.4** ± 0.9
C14:1	ND	0.2 ± 0.1	ND	0.1 ± 0.02	ND	ND	0.1 ± 0.04	ND	0.1 ± 0.0
C16:1	1.2 ± 0.9	5.0 ± 1.0	4.1 ± 1.1	9.8 ± 1.4	5.8 ± 0.7	1.7 ± 0.4	7.9 ± 3.5	1.1 ± 0.1	4.6 ± 0.3
C17:1	ND	ND	ND	ND	ND	ND	ND	ND	ND
C18:1n9t	0.2 ± 0.1	ND	0.1 ± 0.0	0.1 ± 0.0	ND	0.1 ± 0.1	0.4 ± 0.1	0.2 ± 0.0	0.3 ± 0.0
C18:1n9c	6.7 ± 1.5	22.6 ± 4.6	20.1 ± 1.2	39.5 ± 6.4	20.1 ± 4.9	5.2 ± 3.9	6.4 ± 1.3	38.2 ± 1.1	26.6 ± 2.5
C20:1	0.1 ± 0.1	1.1 ± 0.9	0.5 ± 0.3	1.4 ± 0.7	1.7 ± 0.3	0.4 ± 0.1	0.7 ± 0.02	0.6 ± 0.09	0.8 ± 0.1
C22:1	0.1 ± 0.0	0.5 ± 0.3	0.2 ± 0.1	0.2 ± 0.1	3.7 ± 0.8	0.9 ± 0.5	0.8 ± 0.2	0.1 ± 0.1	0.6 ± 0.3
C24:1	0.3 ± 0.1	1.3 ± 0.2	1.1 ± 0.1	ND	0.3 ± 0.1	0.2 ± 0.1	0.1 ± 0.0	ND	0.1 ± 0.0
∑MUFA	**8.5** ± 2.1	**30.7** ± 4.7	**26.1** ± 0.9	**51.1** ± 5.3	**31.6** ± 4.0	**8.5** ± 4.6	**16.4** ± 5.1	**40.2** ± 1.1	**33.1** ± 2.4
C18:2n6t	ND	ND	0.1 ± 0.0	ND	ND	ND	ND	ND	ND
C18:2n6c	1.4 ± 0.2	4.4 ± 0.8	3.6 ± 0.3	7.3 ± 0.8	6.5 ± 2.3	1.0 ± 1.4	0.7 ± 0.2	9.5 ± 1.9	14.9 ± 1.2
C18:3n6	0.1 ± 0.0	ND	0.1 ± 0.0	0.2 ± 0.0	0.1 ± 0.0	ND	0.1 ± 0.0	0.3 ± 0.1	0.9 ± 0.1
C18:3n3	2.0 ± 0.5	5.3 ± 0.7	6.0 ± 1.1	5.9 ± 2.4	7.2 ± 1.2	0.4 ± 0.2	5.0 ± 1.8	1.4 ± 0.3	3.9 ± 0.7
C18:4n3	0.5 ± 0.1	1.4 ± 0.4	1.1 ± 0.2	0.3 ± 0.3	0.5 ± 0.1	0.2 ± 0.0	0.3 ± 0.1	ND	0.1 ± 0.1
C20:2n6	0.4 ± 0.1	0.7 ± 0.2	1.2 ± 0.1	1.2 ± 0.6	1.6 ± 0.5	0.8 ± 0.2	1.1 ± 0.2	2.1 ± 0.3	3,2 ± 0.2
C20:3n6	0.1 ± 0.1	ND	0.1 ± 0.0	0.2 ± 0.0	0.1 ± 0.0	ND	ND	0.7 ± 0.1	0.7 ± 0.1
C20:3n3	0.1 ± 0.0	0.5 ± 0.2	0.6 ± 0.1	0.1 ± 0.1	0.5 ± 0.1	ND	0.1 ± 0.1	0.1 ± 0.0	0.5 ± 0.1
C20:4n6	2.8 ± 0.7	0.7 ± 0.4	0.8 ± 0.2	1.4 ± 0.5	0.5 ± 0.1	1.1 ± 0.2	3.0 ± 0.7	1.1 ± 0.2	1.9 ± 0.4
C22:2 *cis*	ND	0.5 ± 0.1	ND	ND	ND	ND	0.1 ± 0.02	ND	ND
C20:5n3	7.6 ± 1.1	6.2 ± 1.2	3.8 ± 0.3	2.3 ± 1.3	8.0 ± 3.0	24.6 ± 3.9	25.4 ± 4.1	0.3 ± 0.1	0.5 ± 0.3
C22:5n3	1.6 ± 0.4	0.6 ± 0.1	5.6 ± 0.6	0.9 ± 0.4	3.8 ± 1.7	2.1 ± 0.2	5.4 ± 1.2	0.4 ± 0.1	1.7 ± 0.7
C22:6n3	50.8 ± 5.2	20.4 ± 4.5	26.6 ± 2.1	2.1 ± 1.2	17.5 ± 2.0	40.5 ± 5.0	18.0 ± 4.0	1.7 ± 0.2	3.2 ± 1.1
∑PUFA	**67.4** ± 4.4	**40.7** ± 4.3	**49.6** ± **0.8**	**21.9** ± 5.5	**46.3** ± 3.8	**70.7** ± 6.8	**59.2** ± 4.6	**17.6** ± 2.5	**31.5** ± 2.7
n − 3	62.6 ± 4.7	34.4 ± 4.3	43.7 ± 0.8	11.6 ± 4.7	37.5 ± 6.2	67.8 ± 8.4	54.2 ± 4.5	3.9 ± 0.6	9.9 ± 2.9
n − 6	4.8 ± 0.7	6.3 ± 0.8	5.9 ± 0.5	10.3 ± 1.1	8.8 ± 2.2	2.9 ± 1.4	5.0 ± 0.7	13.7 ± 2.1	21.6 ± 1.2
EPA	7.6 ± 1.2	6.2 ± 1.2	3.8 ± 0.2	2.3 ± 1.4	8.0 ± 3.0	24.6 ± 3.9	25.4 ± 4.2	0.3 ± 0.1	0.5 ± 0.4
DHA	50.8 ± 5.2	20.4 ± 4.5	26.6 ± 1.0	2.1 ± 1.3	17.5 ± 2.0	40.5 ± 5.0	18.0 ± 4.0	1.7 ± 0.3	3.2 ± 1.5
EPA + DHA	58.4 ± 5.3	26.6 ± 4.9	30.4 ± 1.1	4.4 ± 2.4	25.5 ± 4.8	65.1 ± 2.5	43.4 ± 6.1	2.0 ± 0.3	3.7 ± 1.5
n − 3:*n* − 6	13.0 ± 2.5	5.5 ± 1.8	7.4 ± 0.9	1.1 ± 0.4	4.3 ± 3.1	23.4 ± 7.9	10.8 ± 2.1	0.3 ± 0.1	0.5 ± 0.2
DHA/EPA	6.7 ± 1.2	3.3 ± 1.0	7.0 ± 1.0	0.9 ± 0.3	2.2 ± 0.7	1.7 ± 0.2	0.7 ± 0.2	5.7 ± 1.4	6.4 ± 1.7

Latin names fish species analysed – cod (*Gadus morhua callaries*); herring (*Clupea harengus membras*); Baltic salmon (*Salmo salar*); carp (*Cyprinus carpio*); trout (*Oncorhynchus mykiss*); walleye pollock (*Theragra chalcogramma*); sole (*Limanda aspera)* sutchi catfish (*Pangasius hypophthalmus)* tilapia *(Oreochromis niloticus),*
ND – not detected.

17.6 ± 2.5%, carp 21.9 ± 5.5%, tilapia 31.5 ± 2.7%). This is linked to differences in the diets of farmed and wild fish. As reported by Hung, Suhenda, Slembrouck, Lazars, and Moreau (2004) and Rahman, Islam, Halder, and Tanaka (2006), the fatty acid profile of the muscle tissues of sutchi catfish, despite certain genetic predispositions, was largely dependent on the diet they were fed during rearing. Sutchi catfish farmed in Vietnam and China are fed diets composed primarily of vegetable origin components. It is widely known, that dietary composition, and especially the diet's fatty acid profile, has a qualitative and quantitative impact on the fatty acid composition of fish lipids (Henderson & Tocher 1987; Steffens 1997).

The percentage share of DHA in the lipids extracted from the Baltic fish analysed (salmon, cod) substantially exceed that of EPA. The ratio of DHA/EPA in the lipids extracted from the analysed Baltic salmon and cod was 7.0 ± 1.0 and 6.7 ± 1.2, respectively. A much lower ratio of these acids (1.9) was reported by Iverson, Frost and Lang (2002) for Pacific cod (*Gadus macrocephalus*). Relatively high ratios of DHA/EPA were currently measured in the lipids of imported farmed fish: 5.7 ± 1.4 for sutchi catfish and 6.4 ± 1.7 for

tilapia. The lowest ratio of DHA/EPA was noted in carp farmed in Poland (0.9 ± 0.3) and in sole from the Pacific (0.7 ± 0.2). Whelen (2009) reports that high ratios of DHA/EPA have an advantageous impact on consumer health and that DHA is more efficient than is EPA in reducing the risk of coronary heart disease.

As mentioned in the introduction, according to several scientists (Kolanowski, 2000; Leskanich & Noble, 1997; Simopoulos, 2002), the prophylactic activity of fatty acids is also a function of the $n-3$ to $n-6$ acid ratio. The optimal ratio of these acids should be 1:5 (0.2) (Sargent 1997). The majority of the fish analysed had much higher ratios of $n-3$:$n-6$ acids. This was particularly noted in the marine fish species, such as walleye pollock ($n-3$:$n-6$ – 23.4 ± 7.9), cod ($n-3$:$n-6$ – 13.0 ± 2.5), and sole ($n-3$:$n-6$ – 10.8 ± 2.1). Huynh and Kitts (2009) who also studied walleye pollock from the Pacific, reported a similar ratio of $n-3$:$n-6$ acids in the lipids of this fish at 18.66. In the current study, the lowest ratio of $n-3$:$n-6$ acids was noted in sutchi catfish ($n-3$:$n-6$ – 0.3 ± 0.1) and tilapia ($n-3$:$n-6$ – 0.5 ± 0.2), which are both farmed imports. Carp farmed in Poland also had a low ratio of $n-3$:$n-6$ acids at 1.1 ± 0.4.

Young (2009) in his review article reported that the ratio of $n-3$:$n-6$ acids in farmed tilapia did not exceed 1. According to this same author, the ratio of these acids in wild tilapia differs due to the fact that the diet of wild fish contains higher contents of $n-3$ than $n-6$.

The current study indicated that the $n-3$:$n-6$ ratio in the lipids of wild fish is much higher than that in farmed fish. However, high ratios of $n-3$ to $n-6$ acids in the lipids of wild fish is not always found. In addition to genetic predisposition, this ratio depends largely on the location in which the fish are caught. This is because location determines the composition of the available food base in that area. Gokce, Tasbozan, Celik, and Tabakoglu (2004) reported 1.45–3.84 for sole (*Solea solea*) from the Mediterranean. Gladyshev, Sushchik, Gubanenko, Dermirchieva, and Kalachova (2007) reported 4.81 for sea trout (*Salmo trutta*) from the waters surrounding Norway. Guler, Kiztanir, Aktumsek, Citil, and Ozparlak (2008) reported 0.5–1.06 for carp (*Cyprinus carpio* L.) caught near the coast of Turkey. Mnari et al. (2007) reported 1.02 for gilthead seabream (*Sparus aurata*) caught near the Tunisian coast. Özogul, Özogul & Alagoz (2007) reported 1.7 for European seabass (*Dicentrarchus labrax)* caught off of the coast of Turkey.

The consumption of $n-3$ to $n-6$ fatty acids in the modern Western diet is estimated to be about 1:20–25. In contrast, it is probable that our Paleolithic ancestors consumed a diet rich in $n-3$ acids with an estimated $n-3$:$n-6$ ratio of 1:1 (Block & Pearson, 2006). Such a dramatic nutritional regression is the result of a decrease in fish consumption and the result of the development of civilisation. Today, the amount of $n-3$ acids in meat and fish is much lower. The application of commercial fodder that contains high levels of $n-6$ acids and low levels of $n-3$ acids is the underlying reason. Even cultivated vegetables are poorer in omega−3 acids than are plants that grow in the natural environment (DeFillippies & Sperling, 2006).

Generally, fish lipids and fish products have a much higher $n-3$:$n-6$ ratio than is recommended (1:5), and from a nutritional standpoint this is highly beneficial and desirable for the daily human diet. The $n-3$:$n-6$ ratios in other foodstuffs is considerably lower than that recommended. For example, this ratio ranges from 1:10 to 1:20 in animal lipids, while in vegetable oils that are used widely in households, these ratios range from 1:15 to 1:200.

3.3. Fatty acid concentrations in mg/100 g muscle tissue

The American Heart Association (AHA), in its 2003 recommendations, suggests that people with diagnosed coronary heart disease (CHD) should consume approximately 1 g of EPA and DHA each day. People without any symptoms of CVD (cardiovascular disease) should consume approximately 500 mg of these acids daily for prophylactic purposes. However, higher doses of these acids are necessary to reduce very high triglycerides levels found in the blood. The AHA reports that an intake of approximately 2–4 g of EPA + DHA each day can lower triglycerides by 20–40% (Kris-Etherton, Harris, & Appel, 2003). Though, due to the risk of bleeding resulting from the intake of $n-3$ fatty acids (particularly at doses greater than 3 g/day), a physician should be consulted before starting treatment with this dose. This is why the benefits of including fish in the diet depends on the content of $n-3$ fatty acids (including EPA + DHA) in the portion of fish consumed.

The high percentage share of EPA + DHA in the lipids extracted from the muscle tissues of walleye pollock and cod was not reflected in high concentrations, expressed as mg/100 g in the muscle tissues of these two species. Since walleye pollock and cod had very low lipid contents, the concentration of total EPA and DHA in their muscle tissues was 56.0 ± 13.2 mg/100 g and 44.7 ± 7.0 mg/100 g, respectively (Table 3). However, the lowest content of these acids was determined in the muscle tissues of farmed sutchi catfish from Vietnam (24.8 ± 5.7 mg/100 g). Slightly higher concentrations

Table 3
Fatty acid content (mg/100 g muscle tissue) in chosen species of fish available on the Polish market (mean value ± SD or SD in parentheses).

Fatty acids mg/100 g	Cod	Herring	Baltic salmon	Carp	Trout	Walleye pollock	Sole	Sutchi catfish	Tilapia
SFAs	18.4 ± 5.4^{f}	1011.6^{c} (326.2)	3043.3^{a} (559.3)	1316.4^{bc} (704.4)	1563.4^{b} (345.2)	17.9 ± 7.0^{f}	116.6^{e} (58.7)	524.4^{d} (95.6)	676.8^{d} (182.1)
MUFAs	6.5 ± 2.4^{f}	1085.9^{c} (478.3)	3268.7^{a} (549.7)	2491.1^{b} (1622.1)	2235.5^{b} (660.3)	7.3 ± 6.5^{f}	78.3^{e} (47.4)	499.6^{d} (105.0)	632.8^{cd} (189.1)
PUFAs	51.6 ± 8.6^{f}	1439.6^{c} (466.0)	6211.7^{a} (1066.2)	1067.8^{c} (372.5)	3275.4^{b} (506.3)	60.8 ± 14.3^{f}	283.0^{e} (163.0)	218.7^{e} (63.2)	608.0^{d} (131.1)
$n-3$	47.88 ± 7.7	1216.8 (380.6)	5472.8 (954.7)	565.6 (147.5)	2652.9 (368.3)	58.3 ± 13.6	259.1 (152.9)	48.5 (11.1)	189.3 (26.0)
$n-6$	3.7 ± 1.0	222.8 (73.1)	738.9 (91.0)	502.2 (215.2)	622.5 (219.2)	2.5 ± 2.0	23.9 (8.9)	170.2 (46.5)	413.0 (93.7)
EPA	5.8 ± 1.2	219.3 (89.7)	475.9 (93.0)	112.1 (54.4)	566.0 (144.5)	21.2 ± 5.3	121.4 (88.1)	3.7 ± 1.5	9.6 ± 1.3
DHA	38.9 ± 6.2	721.6 (226.2)	3331.3 (575.4)	102.4 (12.0)	1238.0 (191.5)	34.9 ± 8.1	86.0 (42.7)	21.1 ± 4.6	61.2 ± 7.2
EPA + DHA	44.7 ± 7.0^{f}	940.9^{c} (306.6)	3807.2^{a} (666.3)	214.5^{d} (62.1)	1804.0^{b} (279.2)	56.0 ± 13.2^{f}	207.4^{d} (125.4)	24.8 ± 5.7^{g}	70.8 ± 6.7^{e}

Latin names fish species analysed – cod (*Gadus morhua callaries*); herring (*Clupea harengus membras*); Baltic salmon (*Salmo salar*); carp (*Cyprinus carpio*); trout (*Oncorhynchus mykiss*); walleye pollock (*Theragra chalcogramma*); sole (*Limanda aspera)* sutchi catfish (*Pangasius hypophthalmus)* tilapia *(Oreochromis niloticus),*
The superscript notations ^{a,b,c,d,e,f,g} denote significant differences ($p < 0.05$) among all the fish species.

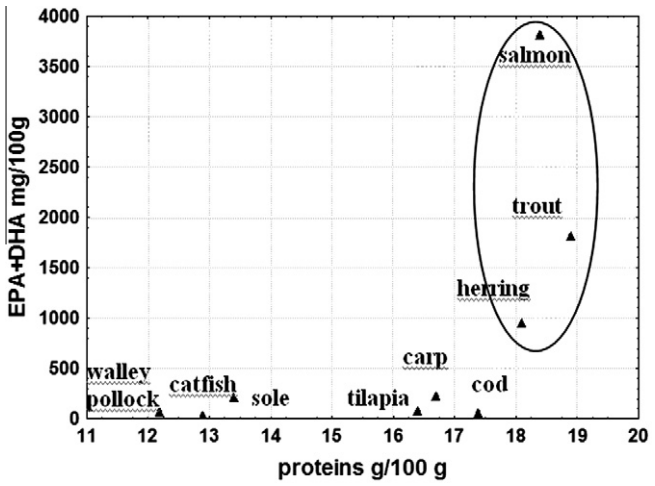

Fig. 1. Comparison of nutritional qualities of the fish species analysed in terms of protein content, and EPA and DHA contents.

of these acids were measured in the muscle tissues of farmed tilapia from China (70.8 ± 6.7 mg/100 g). The mean contents of EPA + DHA in the muscle tissues of carp farmed in Poland and sole from the Pacific Ocean were slightly higher than 200 mg/100 g at 214.5 ± 62.1 mg/100 g and 207.4 ± 125.4 mg/100 g, respectively.

The highest concentration of EPA + DHA among the fish analysed was noted in the muscle tissues of Baltic salmon (3807.2 ± 666.3 mg/100 g). High concentrations of these acids were also noted in the muscle tissue of trout farmed in Poland (1804.0 ± 279.2 mg/100 g). The muscle tissue of Baltic herring had a lower content of EPA + DHA (940.9 ± 306.6 mg/100 g) since the lipid content of this fish was also lower. Huynh and Kitts (2009) reported that Pacific herring (*Clupea harengus pallasi*) contained EPA + DHA at a much higher level of 1680 mg/100 g tissue. This herring, however, had a higher lipid content (10.78 ± 0.68%), but a lower percentage share of EPA + DHA in the total pool of all the fatty acids (17.32%).

4. Nutritional value assessment

The nutritional value of the nine fish species tested is shown in Fig. 1

4.1. Baltic fish (cod, herring, salmon)

The muscle tissues of Baltic fish have high protein content (over 17%) that is 98% digestible. Cod is a very lean fish, herring is moderately fatty, and salmon is very fatty. The lipid content is linked to the energy value of the muscle tissues of fish, and in these fish the average energy values were: 295.8 kJ/100 g for cod, 446.6 kJ/100 g for herring, and 797.5 kJ/100 g for salmon. Cod cannot be classified as a fish that is significant in the prevention of coronary heart disease, because of the low content of acids from the $n-3$ family, including EPA and DHA. Salmon, however, which contains an average of more than 3800 mg/100 g of EPA + DHA, could be recommended to patients with cardiovascular system diseases. Just two 100 g portions of salmon per week should meet the EPA and DHA requirements for people with coronary heart disease. Nonetheless, when that species is consumed the issue related to contamination with dioxins (PCDD/F) and dioxin-like polychlorinated bifenyls (dl-PCBs) should be considered (Szlinder-Richert, Barska, Usydus, Ruczynska, & Grabic, 2009; Usydus et al., 2009). In contrast, 100 g portions of Baltic herring would have to be consumed seven days per week to achieve similar effects.

4.2. Fish farmed in Poland (carp, trout)

The muscle tissues of trout had higher protein content (18.9 ± 0.8%) than that of carp (16.7 ± 0.8%). The digestibility of the protein in both species exceeded 98%. The average energy value of the carp muscle tissues was 472.6 kJ/100 g, while that of trout was 595.1 kJ/100 g. Carp is not a species of fish that should be recommended to people suffering from coronary heart disease because it has relatively low concentrations of EPA and DHA (214.5 ± 62.1 mg/100 g tissue) and a low ratio of $n-3$:$n-6$ acids (1.1 ± 0.4). Trout, however, which has significantly higher contents of total EPA and DHA (1804.0 ± 279.2 mg/100 g tissue) is recommended to be included in the diet and particularly in the diets of those with cardiovascular diseases. Two 200 g portions of trout weekly should meet the requirements for EPA and DHA by persons with coronary heart disease.

4.3. Oceanic fish imported from China (walleye pollock, sole)

The muscle tissues of walleye pollock and sole had relatively low protein (12.2 ± 2.0% and 13.4 ± 1.3%, respectively) and lipid (0.09 ± 0.03% and 0.5 ± 0.3%, respectively) contents. The digestibility of protein in both species is high at 97%. The average energy value of the walleye pollock muscle tissue was 210.7 kJ/100 g, while that of sole was 246.3 kJ/100 g. The low lipid content was reflected in the low concentrations of total EPA + DHA (walleye pollock – 56.0 ± 13.2 mg/100 g tissues, sole – 207.4 ± 125.4 mg/100 g tissues). This is why these species are not recommended for those with coronary heart disease despite the very beneficial ratio of $n-3$:$n-6$ acids in walleye pollock (23.7 ± 7.9).

4.4. Farmed fish imported from Vietnam and China (sutchi catfish, tilapia)

The muscle tissue of sutchi catfish, had a low protein content (12.9 ± 0.8%), while the protein content of the muscle tissues of tilapia was significantly higher (16.4 ± 0.6%). The protein digestibility in both species exceeds 98%. The average energy values of the sutchi catfish muscle tissues was 267.4 kJ/100 g, while that of tilapia 352.8 kJ/100 g. Sutchi catfish and tilapia had the lowest $n-3$:$n-6$ acid ratios among the fish analysed at 0.3 ± 0.1 and 0.5 ± 0.2, respectively, and the total concentration of EPA and DHA in these fish species was also very low (sutchi catfish 24.8 ± 5.7 mg/100 g tissue; tilapia 70.8 ± 6.7 mg/100 g tissue). These fish are not recommended for cardiovascular disease prevention, because they have low levels of EPA and DHA, and low $n-3$:$n-6$ ratios.

5. Conclusions

The fish imported from China and Vietnam (walleye pollock, sole, sutchi catfish and tilapia) are characterised by low contents of EPA and DHA, and therefore it can be stated, that they are not significant for coronary heart disease prevention. Baltic cod and carp farmed in Poland are also not significant for coronary heart disease prevention. The increasing popularity of fish imported from China and Vietnam on the Polish market is due to their culinary properties. They are purchased as skinned fillets, the texture of their meat is firm, and, after cooking, they do not give off a typically "fishy" smell.

In turn, Baltic salmon, Baltic herring and trout farmed in Poland thanks to their high contents of EPA and DHA and beneficial $n-3$:$n-6$ ratios can play a significant role in preventing cardiovascular system diseases. The AHA recommends a daily intake of 1 g of EPA + DHA for patients with heart disease (McNamara,

2006). The results obtained in this study indicated that this recommended dose (1 g) of EPA and DHA was contained in about 25 g of Baltic salmon, about 100 g of Baltic herring, about 55 g of trout farmed in Poland and in more than 4000 g of sutchi catfish.

The study conducted indicated that there is a large variation in the fat content and beneficial fatty acid content in fish species popular on the Polish market. It means that consumers should make a conscious choice between culinary properties and nutritional quality of fish consumed.

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