Polar and neutral lipid composition and fatty acids proﬁle in selected ﬁsh meals depending on raw material and grade of products

Adriana Mikaa, \*, Ewa Swiezewskab, Piotr Stepnowskia

a Department of Environmental Analysis, Faculty of Chemistry, University of Gdansk, 80-308, Gdansk, Poland

b Institute of Biochemistry and Biophysics, Polish Academy of Sciences, 02-106, Warsaw, Poland

\* Corresponding author. Wita Stwosza 63, 80-308, Gdansk, Poland.

ABSTRACT

Fish and ﬁsh products are widely distributed feed in aquaculture and agriculture. However, still little is known on the lipid composition of them, potential differences in the lipid proﬁles of various meals depending on ﬁsh composition of meal and process technology. Therefore, the aim of this study was to determine the characteristics of polar and neutral lipids in selected meals. The thirteen ﬁsh meals were analyzed using two mass spectrometry technique coupled with gas chromatography and liquid chromatography. The highest lipid content was detected in mixed meal prepared from many species e multi ﬁsh meal e (mackerel, trout, sprat, herring, perch, silver carp etc.). In our article for the ﬁrst time such precise fatty acid proﬁle including atypical acids, e.g. branched fatty acid, was described in ﬁsh meals. Polyunsaturated fatty acids (PUFA) dominated in Norsea Mink (Nsm), Mauretania Grade (MG), Human Grade Batch (HGB) and Low Temperature (LT) products, what was associated with the processing technique and whole ﬁsh was used for meal production. These products were also abundant in phospholipids. Meals did not subjected to extrusion process and without addition of antioxidant were characterized by low levels of n-3 PUFA and small diversity of polar and neutral lipids.

1. Introduction

Millions of tonnes of ﬁsh meal are produced and used in com- mercial diets for ﬁsh, dairy cattle, mink, poultry and swine (Aberoumand, 2010). In ﬁsh feed industry exist two types of animal feed, produced from whole fresh industrial ﬁsh and from ﬁsh offal (Jensen, Fiskeindustri, & Denmark, 1990). In 2008 world production of ﬁsh meal amounted about 5 million tons (Penven, Perez-Galvez, & Berge', 2013) and currently, the supply is stable at 6.0 to 6.5 million tons annually (Miles and Chapman, 2006). In order to produce 1 ton of dry ﬁsh meal, 4 to 5 tons of whole ﬁsh are required (Miles and Chapman, 2006). Fish meals can be divided into 3 cat- egories: ﬁsh meal made from ﬁsh, which are not suitable for human consumption (sandeel, Norway pout), ﬁsh meal made from ﬁsh, which can be consumed by human (blue whiting, sprat, capelin) and ﬁsh meal produced from ﬁsh, which are commonly consumed by human, but any surplus may be used for ﬁsh meal production (herring, mackerel) (Karalazos, 2007).

Balance of amino acids, fatty acids and phospholipids are essential for optimum growth, development and reproduction (Miles and Chapman, 2006; Usydus, Szlinder-Richert, Adamczyk, & Szatkowska, 2011). Until now, authors mainly analyzed content of protein and amino acids composition in ﬁshery products and in commonly available speciﬁcation of ﬁsh products are presented mainly: total amount of protein, fat, water, salt, volatile nitrogen, minerals. Despite application of ﬁsh meal in agriculture and aquaculture and beneﬁcial effects of ﬁsh meal, we still lack an ac- curate characteristics of their lipids. Only few previous studies analyzed the proﬁles of polar (PL) and neutral lipids in ﬁsh meal (Vik et al., 2015). Importantly, lipid content and stability of ﬁsh meal depends on storage conditions and processing, seasonal variations and ﬁshery location (Samuelsen, Mjøs, & Oterhals, 2014) as well as presence of natural antioxidant (Bragado'ttir, Pa'lmado'ttir, & Kristbergsson, 2004). Other conditions, such as species of ﬁsh and part of organism intended for meal production will determine the dominant group of lipids (Jensen et al., 1990). Therefore, the objective of this research was to identify the composition of molecular species of speciﬁc lipid classes in ﬁsh meal, which is produced in various technology process from whole ﬁsh (homogeneous meal) and from by-products of several species of ﬁsh (mixed meal). Characterization of lipids comprises a new information about the lipid composition in ﬁsh products. Two mass spectrometry (MS) technique was used. The total number of FAs was analyzed by using gas chromatographyemass spectrometry (GCeMS) technique with electron ionization (EI). Diacylglycerols (DAGs), triacylglycerols (TAGs), lysophospholipids (LPLs), phos- pholipids (PLs), ceramides and sphingomyelins were recorded using a liquid chromatography-electrospray-tandem mass spectrometry (LC-ESI-MS2) technique with Ultra Ion Trap and detector MS via diode array detector (DAD).

2. Material and methods

2.1. Experimental material

Fish meals from several ﬁshing companies were purchased. Research material was divided into three parts: homogeneous meals produced in low temperature process (LT): (1) Blue Whiting, (2) Baltic Sprat, (3) Boar Fish, (4) Capelin and (5) Sandeel; Norsea Mink (Nsm) homogeneous and mixed meals: (6) Sprat, Norway pout and Herring, (7) Sprat and Norway pout, (8) Sprat, (9) Mauretania Grade (MB) Tobias and (10) Human Grade Batch (HGB) Sardinella. The last part of analyzed ﬁsh meals were multi meals: (11) before extrusion without antioxidant, (12) after extrusion with antioxidant and (13) after extrusion without antioxidant. Naturox as an antioxidant were added to the all ﬁsh meals, except ﬁsh meal 11 and 13.

2.2. Chemicals and reagents

Methanol, chloroform, isopropanol, acetonitrile, n-hexane, chloric acid, acetic acid, potassium hydroxide, sodium chloride and ammonium acetate were obtained from Avantor (Gliwice, Poland). All the solvents were HPLC grade. Saturated branched chain fatty acid 19-methyl-eicosanoate was used as an internal standard for GCeMS analysis with a 10% BF3 in methanol, both obtained from SigmaeAldrich (Poznan, Poland). neutral lipid standards used in the chromatographic analysis were: dilaurin (DAG), trimyristin (TAG); and PLs standards: 1,2-dipalmitoyl-sn-glycero-3- phosphocholine (PC), 1,2-dioleoyl-sn-glycero-3- phosphoethanolamine (PE), 1,2-dimyristoyl-sn-glycero-3- phospho-L-serine (PS), and sphingosine 1-phosphate (SM) and N- Hexanoyl-D-sphingosine (Cer), also obtained from/provided by SigmaeAldrich (Poznan, Poland). Aminopropyl cartriges Strata™ (500 mg/6 ml matrix) were from Phenomenex (USA).

2.3. Sample preparation

The ﬁsh meals were lyophilized and extracted in a chloroform- methanol mixture (2:1, v/v) (Folch, Lees, & Stanley, 1957). The lipid extracts were dried by evaporation under a stream of nitrogen. Each sample was divided into two parts: for the analysis of FA compo- sition by using GCeMS technique and for the analysis of complex lipids, namely polar lipids (ceramides, sphingolipids and phos- pholipids) and neutral lipids (di- and triacylglycerols) by using LC-ESI-MS2 technique. The lipid extracts were frozen at -20 o C in glass amber tubes and stored until analysis. The lipid standards were prepared and analyzed according to the identical protocol as the investigated material.

2.4. Spectrometric techniques

2.4.1. GCeMS analysis

FA proﬁles of the ﬁsh meal lipids were determined using GCeMS technique for methyl esters. The lipid extracts were hydrolyzed with 1 mL of 0.5 M KOH in methanol and incubated at 90 o C for 3 h. Subsequently, FAs were extracted by n-hexane and the n-hexane phase was evaporated to dryness under a stream of nitrogen. Finally, 0.1 mL of 10% BF3 in methanol was added and the samples were incubated at 55 o C for 1.5 h. The samples were frozen at -20 o C until the GCeMS analysis. The proﬁle of fatty acid methyl esters (FAMEs) was determined using the GCeMS on a QP-2010 SE chromatograph (Shimadzu, Tokyo, Japan) with a 30 m x 0.25 mm i.d. fused silica capillary column Rtx-5 (Restek Corporation, USA) and a 0.25-mm thick ﬁlm. The temperature of the process was set at 60e300 o C at a 4 o C/min rate, with a 60 kPa helium carrier gas pressure at a column head. Prior to the GCeMS, FAMEs were diluted in dichloromethane.

2.4.2. LC-ESI-MS2 analysis

Mixture lipids were separated on the lipid group by the solid phase extraction (SPE) on aminopropyl cartridges according to Kaluzny, Duncan, Merrit, and Epps (1985) and Bodennec et al. (2000). The correctness of SPE method and separated lipids groups were conﬁrmed on the Thin Layer Chromatography (TLC) plates (Silica gel 60 F254, 25 Glass plates 20 x 20 cm, without ﬂuorescence indicator, Merck; Darmstadt, Germany). Lipids were analyzed using a LC instrument (Agilent Technologies 1200series, Santa Clara, USA). The Eclipse XDB-C18 column (4.6 x 250 mm, 5 mm; Agilent Technologies, USA) was used for chromatographic separation, using the MB phase as an A phase (1 mM ammonium acetate in 90% of water and 10% of acetonitrile, pH 3.7) and aceto- nitrile with isopropanol (5:2, v/v) as a phase B (with addition of 0.1% acetic acid). The ﬂow rate was set at 0.8 mL/min, and 35 mL of the sample was injected into the column. The column was ther- mostated at 30 o C. The analysis was conducted on a Bruker Dal- tonics HCT Ultra Ion Trap (Bremen, Germany). The HPLC system was connected to the MS via DAD (wavelength of l ¼ 254 nm). The nebulizer pressure was set at 50 psi, dry gas temperature at 360 o C and dry gas ﬂow rate at 11 L/min. The capillary voltage was ± 4 kV. The mass in the MS spectra ranged between 50 Da and 1500 Da, with a 700 Da target mass.

The instrument was run in positive and negative ion mode. The obtained mass spectra represent average values for three scans. Prior to the LC-ESI-MS2 analysis, the lipid samples were diluted with a mixture of acetonitrile and methanol (1:1, v/v). LC- operation, data acquisition and processing were carried out using a ChemStation for LC systems Rev. B.01.03-SR2 (Agilent Technolo- gies, USA) and esquire Control 6.1 coupled with Bruker Daltonics DataAnalysis 3.4 (Bruker Daltonics, Germany). Speciﬁc components representing various phospholipid classes were identiﬁed with a SimLipid 4.2 software (PREMIER Biosoft International, USA).

2.5. Statistical analysis

The statistical signiﬁcance of differences between the groups was assessed by a one-way analysis of variance (ANOVA) and Tukey's post hoc test used for further determination of signiﬁcance of differences. Differences between the groups were considered signiﬁcant when p < 0.05. All data are presented as means ± SD. The number of individual measurements taken during the GCeMS and LC-ESI-MS2 analyses was 3. SigmaPlot for Windows version 11.0 software was used for all statistical analyses (Systat Software Inc., Germany).

3. Results

3.1. Lipids content

In our research we analyzed LT, Nsm, MG, HGB grade meals and meals before and after extrusion. The total contents of lipids in 13 research meals are presented in Table 1. The lowest values of lipid content were detected in homogeneous LT meals: LTBlue Whiting, LTBaltic Sprat and LTBoar Fish (Table 1). Homogeneous meals, in which were noted the highest values of lipids were: NsmSprat, LTCapelin and HGBTobias. Multi meals (before and after extrusion) differed considerably in lipids contents. In multi meals group the statistically signiﬁcant differences were noted (Table 1). They are produced mainly from viscera and many fat ﬁsh were used for production of meal (Table 1). This can explain the highest content of lipids among investigated ﬁsh products.

3.2. Fatty acid composition

The proﬁles of FAs found in selected ﬁsh meals are presented in Table 2. There were signiﬁcant differences between the mean contents in FAs proﬁle between selected ﬁsh meals (Table 2, Table S1).

The content of saturated fatty acids (SFA) in homogeneous meals ranged from 22.70 ± 0.81% (LtCapelin) to 39.88 ± 1.43% (MBSardi- nella). Similar SFA content to MBSardinella meal was detected in mixed meal LTSprat/Norway pout/Herring. Level of SFA in sprat products was very different, from 29.48 ± 1.05% in LtBaltic Sprat to 34.58 ± 0.63% in NsmBaltic Sprat. In multi meals (ﬁsh meals No. 11e13) low amounts of n-3 PUFA were detected. The reason was part of ﬁsh, which was used in meal production, by-products. The highest amounts of n-3 PUFA were recorded in homogeneous meals and it was range from 22% (HGBTobias, MBSardinella, LtCapelin, LtBaltic Sprat, LTBlue whiting) to 26.82 ± 0.96% in LTSandeel meal.

High levels of n-3 PUFA did not correlate with the levels of n-6 PUFA. Their amounts ranged from 2% in homogenous meals, except MBSardinella and LTSandeel meal, to 4e5% in multi meal (Table 2). Odd- and branched-chain FAs were also detected in our study (Table 2, Table S1). Level of branched FAs was widely varied depending on type of ﬁsh meal or production process and these acids were detected in low amounts. In this group of fatty acid we noted the greatest diversiﬁcation between studied ﬁsh meals (Table 2).

3.3. Polar and neutral lipids composition

3.3.1. Analysis of groups of lipid

Major class of lipids found in the analyzed material are pre- sented in Table 3. PLs and TAGs were the principal lipid classes found in selected ﬁsh meals. In LTBlue Whiting and MBSardinella meal content of polar lipids was very high because PLs dominated in ﬁsh muscles (Table 3). Mixed meals produced from fatty ﬁsh, such as mackerel, sprat and herring had high content of TAGs (Table 3) and the highest levels of lipids (Table 1). In these ﬁsh meals statistically signiﬁcant differences were observed (Table 3). In LTSandeel meal similar levels of polar and neutral lipids were noted (Table 3), although sandeel is fatty ﬁsh. Polar non- phospholipids, such as ceramides and sphingomyelin were also detected but in very low amount (Table 3, Table S2). These lipids are components of by-products and higher levels of non-polar phos- pholipids were recorded in multi meals (Table 3). Additionally Pearson correlation analysis was made between the total content of PLs and total PUFA. We found strong correlation between total PLs and total PUFA (R ¼ 0.76; p < 0.01), that conﬁrms that PLs are the main source of PUFAs in ﬁsh meals.

3.3.2. Analysis of molecular species of lipids

The results of the LC-ESI-MS2 analysis and main identiﬁed mo- lecular species of lipid classes are presented in Tables 4e6. PLs, DAGs and TAGs were identiﬁed on the basis of their fragment ions [M þ H-R1COOH]þ, [M þ H-R2COOH]þ, fatty acid-related fragments, molecular protonated ion [M þ H]þ, sodiated and/or potassiated ion [M þ Na]þ, [M þ K]þ. A Simlipid 4.2 package (PREMIER Biosoft International, USA) was used for the identiﬁcation.

3.3.2.1. Analysis of neutral lipids. The characteristics of 36 TAGs found in our analyzed ﬁsh meals are presented in Table 4. The range of TAG molecular species was from carbon numbers (CN) 42 to 66 within 0e8 double bond. Only one TAG, (12:0/16:0/20:0), was fully saturated. A total of 45% of all identiﬁed TAGs had one unsaturated FA and among them more than 55% had n-3 PUFA. Only four species were detected with two unsaturated FAs. There were: 15:0/18:3/18:3, 18:4/18:4/16:0, 18:2/17:0/22:4 and 18:2/19:0/22:6, recorded mainly in LT meals. TAG species detected in mostly analyzed products included 14:0/15:0/20:5, 15:0/18:3/18:3, 16:0/18:4/18:1, 16:0/18:1/18:1, 18:1/18:1/18:2, 16:1/18:0/24:1 and 20:1/20:1/22:3. The highest relative intensity was recorded in multi meals, how- ever, the highest diversity of TAG species was detected in homogeneous meals, such as MGSardinella, NsmSprat, HGBTobias, LTSandeel and mixed meal e Sprat and Norway pout (Table 4). The lowest diversity was found in LTBlue Whiting, LTBoar Fish and LTCapelin meals. Despite low diversity of TAGs in Boar Fish meal, we found there the highest relative intensity of TAGs. The comparative analysis of TAG species from LT and Nsm products showed varied differences in technology process. Only 11 TAGs species in LTSprat were recorded (Table 4). A total of various 23 DAGs were identiﬁed in analyzed ﬁsh meals during the LC-ESI-MS2 analysis (Table 5). The range of DAG mo- lecular species was from CN30 to 44 within 0e10 double bond. Three of them were fully saturated (15:0/18:0, 17:0/18:0, 18:0/18:0) and six of them had one saturated and unsaturated FA. Four species yielded signals for highly probable fatty acyl n-3 in both sn-1 and sn-2 positions (20:5/20:5, 20:4/20:5, 18:3/22:2 and 20:4/22:6). The higher relative intensity of all DAGs species was detected in mixed meals (Table 5). Despite the considerable diversity of TAG species found in selected ﬁsh meals, DAGs were recorded in higher in- tensity. DAG species detected in most of analyzed products and in highest intensity included 14:1/18:2, 18:0/18:0, 16:1/22:6, 20:5/20:5, 20:4/20:5 and 18:1/22:6. Various DAGs species were found in Nsm ﬁsh meals. Similarly, NsmSprat meal was much more varied than LT product. However, despite smaller heterogeneity of diacylglycerols in LT products and multi meals No. (11e13), only in these meals DAGs with the highest intensity were noted. The group of identiﬁed molecular species included a number of components that seemed to be speciﬁc solely for Norway pout meal (12:0/18:1, 16:0/16:1 and 22:0/22:1) and multi meals No. 12 and 13 (15:0/20:4, 15:0/22:6). The last components will be speciﬁc for trout, salmon or cod (after exclusion remaining ﬁsh presented in other meals) (Table 5).

3.3.2.2. Analysis of phosphatidylcholines. We identiﬁed the lyso-PC containing FAs 18:3, 20:5, 22:2 and O-14:1 (Table 6). The last LPC was detected in all ﬁsh samples except LTSandeel. In turn, LPC20:5 was characteristic for LT products and multi meals, where reached high intensity. A total of 45 PC species were identiﬁed within the PL group. Four species displayed an unsaturated proﬁle (18:3/20:4, 20:5/22:6, 22:6/22:6, 22:2/22:4) (Table 6). 19 PCs species contained unsaturated and saturated FA, and only three contained unsatu- rated and monounsaturated FA in their structures. The most popular PC was 16:0/22:6 expect LTBlue Whiting meal and 20:0/16:0 mainly for mixed meals and MBSardinella meal. Additionally, un- saturated FAs dominated in ﬁsh meals with other grade than LT (No. 6e10). Saturated and monounsaturated FAs dominated in LT products and meals 11e13. Last meals were source of highly various fatty acids. Importantly, LTSprat meal and NsmSprat were very different in PCs composition. Rare species of PCs were identiﬁed in LTSprat meal. Meals of highest diversity were HGBTobias and MGSardinella.

4. Discussion

4.1. Lipids contents

The lipid composition in ﬁsh meal depends on the raw material (Jensen et al., 1990), species of ﬁsh and processing technique (Samuelsen et al., 2014). Lean ﬁsh (e.g., blue whiting, Norway pout) deposited the lipids mainly in liver, while capelin is considered a fatty ﬁsh (Aberoumand, 2010; Barrett, Anker-Nilssen, Gabrielsen, & Chapdelaine, 2002). Moreover, blue whiting is very delicate ﬁsh and its processing occurs on board large freezer vessels (Valtýsson, 2015). Another reason of ﬂuctuations in lipid composition is ﬁshery season and location (Pe'tursdo'ttir, 2010). Petursdottir (2010) analyzed the lipid content in Herring, Capelin and Blue Whiting meals. The lipid content in blue whiting ranged from 6.5% in May to 13.2% in October and in capelin meal ranged from 10.5% in January to 12.6% in July (Petursdottir, 2010). Windsor and Barlow (1981) analyzed the lipids content in raw material which amounted 10% in capelin, 2% in blue whiting and 7% in sandeel. Hertrampf and Piedad-Pascual (2000) reported 9.3% and 8.3% of total dry mas in capelin and sandeel, respectively. Aberoumand (2010) described the several ﬁsh meals (blue whiting, herring and capelin) which were categorized into three grades: LT, Nsm and standard. The major classes of lipids in selected ﬁsh meals (%) detected by LC-ESI-MS2. Results (n ¼ 3) are expressed as mean ± SD.

4.2. Fatty acid composition

Previous articles are focused mainly on proximate analysis and essential amino acids composition (Aberoumand, 2010; Hertrampf & Piedad-Pascual, 2000; Jensen et al., 1990). Informations about FA composition are necessary, because dietary FA composition will inﬂuence on FA proﬁle in analyzed organisms (Karalazos, Bendiksen, Dick, Tocher, & Bell, 2011). Opstvedt (1985) described similar levels of saturated and n-3 PUFA in homogeneous meals as documented in our experiment. These are eicosapentaenoic acid (20:5n-3) and docosahexaenoic acid (22:6n-3), which are essential for many functions in the humans (R- ezanka & Sigler, 2009). The highest values of n-3 PUFA should be detected in fat ﬁsh (Usydus et al., 2011), but in mixed “fatty” meal LTSprat/Norway pout/Herring the lowest amount of 22:6n-3 was detected. This may result from the season of ﬁshing. According to our earlier study, higher level of 22:6n-3 will be recorded in muscle of ﬁsh not in liver (Mika, Golebiowski, Skorkowski, & Stepnowski, 2012), what was detected in our ma- terial as well. Moreover,Saito and Okabe (2012) analyzed the composition of FA in cultured and wild ﬁsh. Higher levels of 22:6n-3 than 20:5n-3 were observed in farmed ﬁsh, which originate from their dietary lipids, for example, from ﬁsh oils in feeding-stuffs (Saito & Okabe, 2012). Therefore, changes in fatty acids composi- tion will depend on ﬁsh species, season, nutrition and the locality of harvesting (Usydus et al., 2011).

For the ﬁrst time composition of odd and branched-chain fatty acids (OBCFA) was described in ﬁsh meals. OBCFA are produced mainly in plants. Their presence in ruminants (milk and adipose tissue) is high, mostly due to food intake rich in OBCFA (Vlaeminck, Fievez, Cabrita, Fonseca, & Dewhurst, 2006). But, Rodriguez et al. (1997) reported the presence and production of odd-chain acids in hepatocytes of trout. According to authors, odd-numbered acids are elongated and desaturated in ﬁsh tissues (Rodriguez et al., 1997). Their amounts in marine ﬁsh oil can be up 1e4% (Rezanka & Sigler, 2009) and they can be found in many animal feeding- stuffs, such as cereals, oilseed cakes or ﬁsh meals (Ferrando, 1981). Branched FAs with chain length from C14 to C18 carbon atoms are also created in marine food chain (Fievez, Colman, Castro-Montoya, Stefanov, & Vlaeminck, 2012). They have health- promoting properties, e.g. they reduced/inhibited the cancer cells, they are markers of milk products intake (Vlaeminck et al., 2006; Yang et al., 2000).

4.3. Polar and neutral lipids composition

4.3.1. Analysis of groups of lipid

The available data on the neutral lipids and some of polar lipids composition of ﬁsh meal is sparse. Identiﬁed phospholipid species with choline head group in selected ﬁsh meals using LCdESI-MS2. ND e not detected. LT-Low temperature, Nsm-Norsea mink, MBeMauretania Batch, HGB-Human Grade Batch. Blue W-blue whiting, Blatic S-baltic sprat, Boar F-boar ﬁsh, S/Np/H-sprat/norway pout/herring, S/Np-sprat/norway pout, BeoA-before extrusion without antioxidant, EwA after extrusion with antioxidant, EoA-after extrusion with antioxidant. Numerous diacylglycerols are the second messenger signaling lipid, intermediate in lipid metabolism and they are precursors of the basic membrane components (Carrasco, & Me'rida, 2007). Triacylglycerols are the basic source of energy. Polar lipids are major components of central nervous system, mediators in cell signaling (Vance & Tasseva, 2012). Their contents and ratio of PLs to TAGs depend from many various factors. According to Opstvedt (1985), content of PLs de- pends on season, species of ﬁsh is varied considerably and level of TAGs depends on energy status of organism. Additionally, content of PLs and TAGs depends on the parts of ﬁsh used to production of meal and according to other authors, higher values of PLs are noted in meals, which are produced from whole fresh industrial ﬁsh (Cordier, Brichon, Weber, & Zwingelstein, 2002; Jensen et al., 1990). Phospholipids are mainly components of ﬁsh muscles and they correspond to 79e90% of total lipid mass of lean ﬁsh (Sikorski & Kalakowska, 2003). Similar content of phospholipids and tri- acylglycerols in Capelin meal were also observed by Jensen et al. (1990). However, capelin is fatty ﬁsh and content of TAGs is higher than PLs (Barrett et al., 2002). According to Tocher, Bendiksen, Campbell, and Bell (2008) it is not possible to express homogeneous opinion about recommended levels of lipid classes.

4.3.2. Analysis of molecular species of neutral and polar lipids

The lowest diversity of molecular species of TAGs, DAGs and PCs found in some of analyzed products may result from the con- struction of ﬁsh body, lower stability of components or their lack. As reported by Miles and Chapman (2006) and Petursdottir (2010), blue whiting, boar ﬁsh and capelin are very delicate ﬁsh with high percentage of oil and bones. Nsm, HGB and MG meals were signiﬁcantly varied products. The highest number of polar and neutral lipids were found in these meals (Tables 4e6). Aberoumand (2010) also shown predominance of Nsm meals over other ﬁsh meal grades.

Nonetheless, every of analyzed ﬁsh meal is very good solution for farmed ﬁsh and animals, because alternative source of protein- plant meals, contained slight amounts of PLs (Tocher et al., 2008). High levels of protein, energy, essential amino acids, vitamins and minerals will be witness to the high quality of ﬁsh meal (Aberoumand, 2010). But, in available literature is still lack an ac- curate information of composition of lipids. These components are necessary for sustainable development, growth, maturity and reproduction of ﬁsh (Usydus et al., 2011). The content of lipids depends on season, ﬁshery location (Usydus et al., 2011), individual predispositions of ﬁsh species to accumulate the lipids and unsat- urated FAs as well as, raw material (ﬁsh species) and processing technique of meals (Samuelsen et al., 2014).

5. Summary and conclusions

Our study contributes to increasing knowledge about the quality of popular ﬁsh products. Our manuscript presents, for the ﬁrst time, identiﬁcation of 41 fatty acids methyl esters, 59 different molecular species of neutral lipids (di- and triacylglycerols) and 45 phos- phatidylcholines species. The results of our analysis point to complexity of molecular lipid species found in selected ﬁsh meals. For the ﬁrst time atypical acids, e.g. OBCFA were described in ﬁsh meals and among them wide variation was detected. Norsea Mink, Mauretania Grade, Human Grade Batch and Low Temperature products contained higher content of PUFA in comparison to the other ﬁsh meals. Based on the labels of proﬁle FA we can choose the ﬁsh meal with a more favorable composition of FA, which higher content of PUFA (considered as beneﬁcial for human health) and OBCFA (also reported as beneﬁcial for human health and displaying antitumor activity) as well as lower content of SFA (a FAs with adverse effects). This will be reﬂected by the composition of the FA in the feeding animals organism, and in an indirect way this can inﬂuence on the lipid/FA proﬁle of ﬁnal recipients e humans. Also in Norsea Mink, Mauretania Grade, Human Grade Batch and Low Temperature meals PL fraction was highly polyunsaturated. Fish meals with a high content of phospholipids are valuable food products because they have a lot of PUFA. These data suggest that these ﬁsh meals could be used as a valuable functional ingredient of food or nutraceutical.

Farmed ﬁsh are sensitive to the quality of feedstuffs. Therefore, good quality of feed are essential in aquaculture. Feed market offers a wide variety of ﬁsh meals used in aquaculture and agriculture. However, still little is known on the lipid composition of the meals and potential differences in the fatty acid proﬁles of various types of ﬁsh meals. Our study revealed that the production technique and composition of ﬁsh extremely determines composition of lipids in ﬁsh products.

Future studies should elucidate the exact inﬂuence of ﬁsh meals on lipid composition of food obtained from fed animals.

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Appendix A. Supplementary data

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