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1 **Comparison of oil yield and quality obtained by different extraction procedures from**
2 **salmon (*Salmo salar*) processing byproducts**

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27 **Abstract**

28 The content and composition of lipids in different byproducts (skins, heads, and
29 backbones) from mechanically processed farmed Atlantic salmon were determined and
30 compared with that obtained from wild salmon. Three different procedures were used to
31 establish the optimal conditions of oil extraction (at high temperature – 95°C, “cold”
32 extraction at temperature not exceeding 15°C and enzyme assisted with Alcalase). “Cold”
33 extraction at temperature not exceeding 15°C was very efficient, yielding almost 95% of the
34 oil from skins. In the case of heads the obtained yield of about 71% was not lower than that
35 from extraction performed at 95 °C or extraction supported by enzyme treatment. The
36 peroxide value of oil isolated from the heads using “cold” extraction was at the same level as
37 in oil of the enzyme assisted process, but 4 times lower than in oil extracted at high
38 temperature. The results showed that the content of lipids from in the farmed salmon
39 byproducts the content of lipids was about 45-55% higher than in byproducts of wild salmon ,
40 however the EPA+DHA content was 10-33% lower.

41 **Practical applications:** With “cold” extraction heating which is commonly used for oil
42 recovery in the fish industry could be eliminated and thus the cost of the process would be
43 lower and oxidative changes in the oil reduced. Furthermore, this method based on rules of
44 “green chemistry” can be more attractive and alternative procedure of oil isolation from fatty
45 fish byproducts than those using organic solvents. The fatty fish byproducts such as heads,
46 skins and backbones may be used as a source of valuable oils rich in PUFA. The remaining
47 material after oil isolation can be a source of collagen and gelatin used in the food,
48 pharmaceutical and cosmetic industries and finally of minerals preparation (in the case of
49 heads and backbones) used for enriching animal feed.

50



51 **Introduction**

52 The main characteristic of fish oil is the specifically high content of long-chain
53 polyunsaturated fatty acids (PUFA) from the *n-3* family, such as eicosapentaenoic acid (EPA)
54 and docosahexaenoic acid (DHA), which is not the feature of lipids from other origins.
55 Nowadays, consumption of these fatty acids is too small and it is the reason why
56 supplementation of the diet with fish oil is recommended to reduce the deficiency of *n-3*
57 PUFA.

58 EPA and DHA are highly susceptible to oxidation. Oxidized lipids lose their
59 physiological functions and nutritive value. Moreover, their unpleasant smell also limits their
60 application as food additives. In order to obtain oil suitable for human consumption it is
61 necessary to use extraction methods that ensure high quality of the final product.

62 Fish oil is mainly obtained from whole fish or livers. However, some fish byproducts
63 (especially from fatty fish processing) could serve as a source of good quality fish oil for
64 human consumption [1-6]. The fat content and its composition depend on fish species and the
65 kind of byproducts. The methods for extracting oil from byproducts are similar to those used
66 for whole fish or fillets. Aidos *et al.* [4, 7-9] used steam rendering to recover the oil from
67 byproducts of maatjes herring processing. Chantachum *et al.* [10] showed that optimum
68 conditions for tuna head oil separation involved heating the samples at 85 °C for 30 minutes,
69 followed by pressing. This method was also used to obtain oil from Alaska pink salmon heads
70 and viscera [3, 11], pollock heads, viscera and skins [11] and Atlantic salmon byproducts, like
71 heads, frame bones, skins and downgraded gutted fish [12]. However, high temperature
72 extraction leads to low quality of the product. To improve the oxidative stability and quality
73 of the product the oil must be cold filtered, bleached and deodorized under vacuum [13, 14].
74 A disadvantage of these processes is lower amount of long-chain PUFA in the refined oil than
75 in the crude oil. Some authors propose using lower temperatures during the wet pretreatment



76 of the raw materials [15] or decreasing the pH value of liquid phase below 2 [3] to improve
77 the quality of the products. The low pH deactivates enzymes that accelerate the development
78 of unpleasant taste and odour. Barrier and Rousseau [16] patented a method of oil extraction
79 from eviscerated headless and skinless fish mixed with water at temperature lower than 15 °C.
80 Furthermore, enzymatic tissue pretreatment may be an efficient alternative technique for
81 releasing lipids from fish meat and fishing industry byproducts. Fish oil extraction aided with
82 enzymes is more efficient than classical extraction with organic solvents or wet rendering
83 methods [17]. Dumay *et al.* [18, 19] have showed that it is possible to obtain valuable oil from
84 sardine heads and viscera by commercially available proteases. Isolation of the oil supported
85 by enzymes was successfully used to obtain oil from cod viscera and backbones [20, 21] or
86 Nile perch and salmon heads [22]. The type of enzyme and the reaction conditions should be
87 closely matched to the kind of byproducts. According to Gbogouri *et al.* [17] and Linder *et al.*
88 [23] the most effective enzyme for oil isolation from Atlantic salmon heads was Alcalase®.

89 Solvent extraction and supercritical fluid extraction (SFE) ensure high quality of oil,
90 however, these methods demand expensive equipment [24, 25, 26]. The solvent mixture must
91 meet special requirements, because lipids in the fish tissue can differ in polarity. To avoid
92 oxidation during extraction, the mixture of solvents used must also be effective at low
93 temperatures. Chemical extraction with organic solvents is also used by some authors in
94 laboratory practice to evaluate byproducts as a source of fish oil [5, 6]. SFE is rarely used for
95 isolation of oil from fishing industry byproducts because of high costs. However, comparing
96 to conventional fish oil extraction or enzymatic extraction, SFE may be useful for reducing
97 oxidation [27]. Letisse *et al.* [28] showed that sardine oil obtained using SFE is purer but has
98 lower content of PUFA than oil extracted by hexane.

99 According to Fish Information & Services 2010 the Polish salmon market, mainly
100 Atlantic salmon from Norwegian aquacultures, constitutes one of the largest in Europe. This



101 leads to formation of a large amount of fish byproducts - about 21000 t per year. Byproducts
102 are usually converted into fodder meal, or if they are unsuitable for this purpose, they are
103 directed to the landfills. However, the rational way is utilization of salmon byproducts as a
104 raw material for obtaining collagen, gelatin and oil.

105 The aim of this study was to evaluate the potential of byproducts from mechanical
106 processing of farmed salmon as a source of the health promoting lipids and to establish
107 optimal conditions of oil extraction in respect to yield and quality of the product. Comparison
108 of fatty acid composition of lipids in farmed and wild salmon byproducts was also made.

109 **1. Materials and methods**

110 **1.1. Raw materials and reagents**

111 The skins, heads and backbones from mechanically processed farmed salmons, kindly
112 provided by MORPOL S.A. Poland were used. The particular raw materials with the residues
113 of adhering tissues, scales, meat scraps and fat in partially frozen state were minced in a meat
114 grinder (PA-22-M, Edesa HoReCa Ltd) with 5-mm diameter mesh, mixed, packed in
115 approximately 250 g portions into polyethylene bags, sealed under nitrogen and stored at
116 -20 °C not longer than 30 days before use.

117 Chloroform, methanol, ethanol, diethyl ether, phenolphthalein, sodium and potassium
118 hydroxide were purchased from POCH S.A., Poland. Hexane and potassium iodide were
119 purchased from Merck Poland Company. All chemicals used were analytical grade. For
120 enzymatic extraction of oil Alcalase® AF 2.4L from Novozymes Company was used.

121 **1.2. Analytical procedures**

122 Total nitrogen and ash were determined according to AOAC methods [29] and lipid according
123 to the Folch extraction procedure [30]. The phospholipids were determined as total
124 phosphorous by using colorimetric method according to Totani *et al.* [31].



125 Primary oxidation products – hydroperoxides were determined as peroxide value (PV)
126 according to the PN-EN ISO 3960:2005 Standard [32] and free fatty acids as the acid value
127 (AV), according to the PN-EN ISO 660:1998 Standard [33].

128 The method of transesterification by methyl alcohol in the presence of alkaline catalyst at low
129 temperature (according to PN-EN ISO 5509:2000) was used to convert fatty acids to methyl
130 esters (FAME). The FAMEs were analyzed with Perkin Elmer Autosystem XL gas
131 chromatograph, equipped with a 30 m DB-23 silica capillary column (J&W Scientific) of 0.25
132 mm ID and film coating thickness of 0.25µm. Helium carrier-gas column flow rate was 0.91
133 ml/min. A split-splitless (60:1) injector at 250 °C and flame-ionization detector (FID) at
134 250 °C were used. The column temperature, after an initial isothermal period of 5 min at
135 120 °C, was increased to 180 °C at a rate of 1.5 °C/min, and maintained for 25 min. The
136 temperature was increased again to 210 °C and was maintained for 30 min.

137 1.3. Extraction of oil

138 Three procedures were used for oil extraction.

139 Procedure I (“high temperature”)

140 Water at temperature 50°C was added to the frozen raw heads (1:1, w/v)-and the mixture was
141 mixed with a hand blender (HR 1676/90, Phillips) about 5 minutes to form a homogenous
142 pulp. During this procedure the temperature did not exceed 15°C. Then the pulp was heated at
143 95°C for 30 minutes under reduced pressure (0.02-0.04 MPa) with stirring, cooled under
144 vacuum to room temperature, and centrifuged for 10 minutes at 8000xg. The oil from the
145 upper phase was collected by using automatic pipette, the solid residues were discarded and
146 the liquid phase was centrifuged again. The separated oil was collected and combined with the
147 previously obtained fraction.

148 Procedure II (“cold” extraction)



149 Water at temperature 50°C was added to the frozen raw material (heads, skins and backbones,
150 separately) (1:1, w/v) and the mixture was mixed with a hand blender (HR 1676/90, Phillips)
151 about 5 minutes to form a homogenous pulp. During this procedure the temperature did not
152 exceed 15°C. The pulp was then centrifuged 10 minutes at 8000xg. The oil-protein-water
153 phase was separated from solid residues and was centrifuged again for 5 minutes at 8000xg.
154 The separated oil was collected (by using automatic pipette) and weighed.

155 **Procedure III**

156 Extraction of oil from salmon heads was carried out according to Gbogouri *et al.* [17]. Minced
157 salmon heads were mixed for 15 minutes with water (1:1 w/v) at 55 °C. The pH of the
158 mixture was adjusted to 8.0 with 4 M NaOH and Alcalase® was added at substrate mass
159 concentration of 5%. The enzymatic reaction was carried out at 55 °C for 2 hours under
160 nitrogen with continuous stirring. The pH of reacting mixture was adjusted to 8.0 for every 15
161 minutes with 4M NaOH. After 2 hours the mixture was centrifuged for 30 minutes at 8000xg.
162 The oil was collected from the upper phase and weighed.

163 All procedures of oil extraction were repeated 4-6 times. The results are averages from 4-6
164 replications ± standard deviation (SD).

165 **2. Results and discussion**

166 **2.1. Chemical composition of raw materials and characteristic of the oil**

167 The richest source of oil among the examined byproducts of both farmed and wild
168 salmon, are skins (Table 1). They constituted above 20% of lipids while 14.8% and 15.6% w
169 ere present in heads and backbones, respectively. Higher content of total lipids in salmon
170 heads (amounted to about 20%) reported Linder *et al.* [23] and Gbogouri *et al.* [17]. The
171 byproducts from wild salmon contained less oil than byproducts from farmed salmon -
172 generally about 50% less than in the same type of farmed salmon byproducts. The lipid
173 content in all types of byproducts from wild salmon was similar and reached about 8%. These



174 results are consistent with those obtained by Hamilton *et al.* [24] – skin-on fillets from farmed
175 salmon had more lipids (16.6%) than from wild salmon (6.4%). As would be expected the
176 content of mineral compounds (ash) in the heads and backbones was higher than in the skins
177 for both farmed and wild salmon. For example, the farmed salmon heads contained 4.2% of
178 ash, which can be explained by the presence of bones and gristle, while the farmed salmon
179 skins contained only 2.3% of ash. The same situation was observed in the case of wild
180 salmon, where backbones contained 4.6% of ash and skins contained only 1.5%.
181 Simultaneously, what is obvious, the content of proteins was negatively correlated with the
182 content of minerals (ash).

183 The content of phospholipids in farmed salmon heads and backbones was 30% higher
184 than in skins (Table 2). It results from the fact that the former are rich in nervous tissue (brain
185 and spinal cord), of which phospholipids are important components.

186 The level of peroxides in the oil isolated from skins and backbones of farmed salmon
187 by using Folch procedure did not exceed 0.9 mEq O₂/kg, while in the oil from heads it was
188 about 3 times higher (Table 2). The presence of some amount of blood in the heads is
189 probably responsible for such results. Especially the gills are richly supplied with blood
190 vessels in order to act as a respiratory organ. The autoxidation of hemoglobin is an important
191 reaction responsible for the ability of hemoglobin to accelerate lipid oxidation. Release of the
192 oxygen from oxyhemoglobin leads to formation of methemoglobin and superoxide anion
193 radical [35, 36]. Next, the superoxide radical is rapidly dismutated to oxygen and hydrogen
194 peroxide. Hydrogen peroxide can react with previously formed methemoglobin what causes
195 the formation of a ferryl protein radical – known as an initiator of lipid oxidation [35, 37].
196 Furthermore, when a considerable amount of peroxides is present, iron can be released from
197 heme and participate in oxidation of lipids [36, 38].



198 The free fatty acids content (expressed as mg KOH/g) from particular types of farmed
199 salmon byproducts was low and did not exceed 1.3 mg KOH/g (Table 2). It indicated that
200 significant hydrolytic changes in lipids did not occur during processing and extraction
201 procedure.

202 The fatty acid compositions of wild and farmed salmon byproducts lipids are shown in
203 Table 3.

204 The vast majority of fatty acids present in oil of both farmed and wild salmon were
205 unsaturated, 70-75% of total fatty acids. Gbogouri *et al.* [17] reported similar value (about
206 74%) for the oil isolated by chemical extraction (Folch method) from farmed salmon heads.
207 The content of saturated fatty acids (SAFA) oils of all salmon byproducts-ranged from 18.6%
208 to 23.9% and it was the lowest value in the skins, both from wild and farmed salmon (Table
209 3). The most abundant SAFA in the oils from different fish byproducts was palmitic acid (C
210 16:0), while the amount of oleic acid (C 18:1 n-9) was the largest among monounsaturated
211 fatty acids (MUFA).

212 MUFA content was lower, whereas the PUFA content was higher, in lipids of
213 byproducts from wild salmon than farmed salmon (Table 3). EPA and DHA were the major
214 components among the PUFA in all oils of farmed and wild salmon. However, EPA+DHA
215 content in the oils lipids of farmed salmon byproducts (16.4 – 18.9%) was 10-33% lower than
216 that in the oils of wild salmon (21-24.6%). On the other hand, Blanchet *et al.* [39] showed that
217 the content of EPA+DHA was about 17% higher in oil of meat from farmed than from wild
218 salmon. Probably such differences may be due to the different feed, which highly influences
219 the lipid content and their fatty acid composition. Additionally differences can occur in the
220 same fish depending on the period of development, reproduction and spawning. Therefore, if
221 the farmed and wild salmon used in the experiments are from different stages of development
222 the results can be varied. Furthermore, the amount of EPA+DHA in the oil obtained from



223 wild and farmed salmon byproducts was lower than in oils from other fish species like
224 menhaden (26.4%), sardines (27.5%) and tuna (28%) [40, 41, 42]. Nevertheless, the farmed
225 salmon byproducts constitute an abundant source of EPA+DHA.

226 **2.2. Influence of different extraction procedures on the oils characteristics**

227 Three different procedures were used to isolate oil from salmon byproducts. The yield
228 of the oil obtained by procedure I “high temperature”, which is typical for industrial rendering
229 of oil, reached only about 70% (Table 4) of the content of oil established by using Folch
230 method (Table 1). The reason for the relatively low oil yield can be the high content of
231 phospholipids in salmon heads, which stabilize emulsions and render separation of the oil
232 more difficult. Moreover, according to Chantachum *et al.* [10], such high temperature as
233 95 °C used during extraction can additionally impede the oil release. They found that packed
234 unfolded proteins and trapped lipid droplets were formed under these conditions [10]. The
235 temperature of oil isolation has also a great influence on the oxidative stability of the oil. The
236 oil obtained from heads by using procedure I had the highest PV, about 9 mEqO₂/kg of the oil
237 (Table 4), while the oil obtained by chemical (Folch method) extraction from the same type of
238 byproducts showed 3.5 times lower PV (Table 2). Similar results were reported by Skåra *et al.*
239 (2004) who found that the PV of oil extracted at high temperatures from mixed salmon
240 byproducts (heads, frame bones, skins and down-graded gutted fish) reached about
241 10 mEqO₂/kg of the oil. The content of free fatty acids in the oil obtained by using procedure
242 I (Table 4) was only 8% higher than in the oil extracted by the Folch method (Table 2). This
243 suggests that the temperature has no large impact on hydrolysis of the oil, although the
244 calculated differences were statistically significant.

245 In the next step, the procedure of oil extraction was modified and as the raw material,
246 besides heads, skins and backbones were also used. The homogenized pulp was not heated
247 during extraction. The temperature in the process did not exceed 15 °C when procedure II of



248 extraction (“cold” extraction) was used. This was possible to ensure, because the raw material
249 in partially frozen state was used in experiments. The results showed that the yield of oil
250 depended on the type of byproducts (Table 4). The highest yield of oil was extracted from
251 skins, nearly 95%, while for heads it amounted to 71% and was similar to that obtained when
252 procedure I of extraction was used. The PVs of the oil isolated from all types of byproducts
253 by procedure II (Table 4) were lower or similar to the oil extracted by Folch method (Table 2
254 and Table 4). The content of free fatty acids in oils isolated from all types of byproducts was
255 even lower (for instance in skins AV was two times lower) than in the oil obtained by Folch
256 method. The content of phospholipids in oils from all types of byproducts was much lower
257 than in the oil isolated by using Folch method (Table 4). Polar lipids can be bound to proteins,
258 but using solvent mixture of chloroform-methanol in-Folch method allowed their release from
259 complexes and thus the extracted oil had higher phospholipids content than the oils extracted
260 only by using water (II extraction). However, the amount of phospholipids in the oil isolated
261 from salmon heads (0.15%) by procedure II (cold extraction) was higher than in the oil
262 obtained by procedure I - at high temperature (0.02%) because during heating of the pulp,
263 phospholipids participate in forming of stable emulsions what lowers their separation by
264 centrifugation.

265 The influence of temperature on the oil quality is clearly visible in the case of oils
266 from salmon heads. The PV of oil isolated from heads by using procedure II was 4 times
267 lower and the AV was about 80% lower than in the oil isolated at high temperature (procedure
268 I).

269 Extraction supported by enzyme Alcalase® (procedure III) was used to improve the
270 yield of oil isolation from salmon heads. Some authors reached satisfactory yield of fish oil by
271 using enzymes, for example Gbogouri et al. [17] obtained 92% yield of oil isolation from
272 salmon heads by using Alcalase®. However, in our work the amount of oil extracted from



273 salmon heads in the presence of Alcalase® was similar to that obtained by using the
274 procedure I and procedure II and reached about 70% (Table 4). The PV of the oil (1.6
275 mEqO₂/kg of the oil) was the same as for the oil obtained by using “cold” extraction
276 (procedure II) and lower than in the oils isolated from salmon heads by chemical extraction
277 (Folch method) and procedure I (Table 4). The amount of free fatty acids was lower than that
278 in the oil obtained by Folch method (Table 2) and in the oil obtained by using procedure I, but
279 higher than in the oil extracted by using procedure II (Table 4). The oil isolated from the
280 heads by using enzymes was characterized with high content of phospholipids (1.47%), the
281 value of which was about 10 times higher than in the oils isolated by other procedures (Table
282 4). The enzymes most probably contribute to releasing of phospholipids from the membranes.
283 From the biological point of view, the presence of phospholipids in oil and their consumption
284 is desirable [18].

285 In the oil isolated from all types of byproducts by the “cold” extraction (procedure II),
286 the MUFA content (Table 5) was higher than in the oils obtained by using Folch method
287 (Table 3 and 5). The PUFA and EPA+DHA content in the oil isolated from skins (33.3% and
288 15.4% respectively) was slightly lower than in the oil obtained by Folch method (34.8% and
289 16.9% respectively), but these were statistically significant differences. In the oil from salmon
290 heads (Table 5), the EPA+DHA content (16.7%) was about 20% lower in comparison with
291 the oil extracted by Folch method (18.9%), but only about 10% lower from the oil obtained
292 according to the procedure I or by using Alcalase®.

293 In general it can be concluded that the content of PUFA and EPA+DHA in oils from
294 „cold” extraction of byproducts is very close to those obtained by using procedures I (“high
295 temperature”) and III (“by enzymes”).

296 **Conclusions**



297 This study has shown that the byproducts from mechanically processed salmon could
298 serve as a source of oils rich in PUFA.

299 The “cold” extraction of oil from salmon byproducts shows some advantages in
300 comparison to procedures commonly used in the fishing industry. This process conducted at
301 low temperatures allows achieving high yield of oil and simultaneously inhibits lipid
302 oxidation and thus ensures higher oil quality than in the oil obtained at high temperatures.
303 This is especially important for the oil designed as a food supplement to enrich the diet in
304 PUFAs. Furthermore, with elimination of the heating step the cost of the process is
305 significantly reduced.

306 With “cold” extraction it is possible to obtain similar oil yield and amount of
307 EPA + DHA to the ones obtained in the case of extraction supported by enzymes, but the
308 former is more suitable for this purpose. Use of enzymes has special requirements e.g. exactly
309 defined, usually enhanced temperature, what additionally makes higher the costs of oil
310 isolation.

311 Summarizing, it can be stated, that the “cold” extraction could be an attractive solution
312 for isolating the oil from fatty fish byproducts. This procedure allows achieving the oil from
313 fish skins, backbones and heads with high yield and quality in a simple and cheap way.

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317 **Conflict of interest**

318 There are none financial and commercial conflicts of interest.

319

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438 Table 1. Chemical composition of raw material

Type of salmon byproducts	Total lipids [%]		Total proteins [%]		Ash [%]	
	farmed	wild	farmed	wild	farmed	wild
Heads	14.8±0.68 ^b	8.0±0.15 ^b	14.00±0.13 ^c	16.3±0.50 ^c	3.8±0.45 ^a	3.5±0.24 ^b
Skins	20.2±0.64 ^a	8.6±0.05 ^a	21.19±0.14 ^a	22.9±2.40 ^a	2.3±0.11 ^b	1.5±0.08 ^c
Backbones	15.6±0.39 ^{ab}	7.3±0.02 ^c	16.69±0.05 ^b	18.0±0.14 ^b	4.2±0.14 ^a	4.6±0.38 ^a

439 Results are expressed as means of four measurements ± SD. The values in the columns marked with
 440 different letters (a - c) differ significantly (p<0.05).

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442 Table 2. Chemical characteristic of oil isolated according to Folch procedure from different
443 types of farmed salmon byproducts

Type of byproducts	PV	AV	Phospholipids
	[mEq O ₂ /kg]	[mg KOH/g]	[% of total lipids]
Heads	2.56±0.02 ^a	1.23±0.04 ^a	3.1±0.1 ^a
Skins	0.88±0.01 ^b	0.98±0.02 ^c	2.0±0.0 ^b
Backbones	0.68±0.00 ^c	1.12±0.05 ^b	3.3±0.2 ^a

444 Results are expressed as means of four measurements ± SD. The values in the columns marked with
445 different letters (a - c) differ significantly (p<0.05).

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448 Table 3. Fatty acid composition (% of the total fatty acids) of oils extracted by Folch
 449 procedure from various salmon byproducts

Fatty acid	Wild salmon			Farmed salmon		
	backbones	heads	skins	backbones	heads	skins
SAFA						
C 14:0	3.2±0.0	3.6±0.1	3.2±0.0	4.2±0.4	3.7±0.1	3.9±0.0
C 15:0	0.4±0.0	0.4±0.0	0.3±0.0	0.3±0.0	0.3±0.0	0.3±0.0
C 16:0	15.6±0.2	16.9±0.2	15.0±0.1	11.7±0.3	11.4±0.2	11.9±0.0
C 17:0	0.1±0.0	0.1±0.0	0.1±0.0	0.5±0.0	0.5±0.0	0.5±0.0
C 18:0	2.8±0.1	2.9±0.0	2.5±0.1	2.5±0.0	2.7±0.1	2.5±0.0
C 20:0	0.0±0.0	0.0±0.0	0.0±0.0	0.5±0.0	0.5±0.0	0.5±0.0
ΣSAFA	22.1±0.1 ^b	23.9±0.1 ^a	21.1±0.0 ^c	19.7±0.2 ^d	19.1±0.1 ^c	18.6±0.0 ^f
MUFA						
C 14:1	0.3±0.0	0.3±0.0	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0
C 16:1	0.3±0.0	0.4±0.0	0.4±0.0	0.2±0.0	0.2±0.0	0.2±0.0
C 16:1 n-7	4.0±0.1	4.3±0.1	4.0±0.0	4.7±0.2	4.6±0.1	4.7±0.0
C 17:1	0.5±0.0	0.5±0.0	0.5±0.0	0.4±0.0	0.4±0.0	0.4±0.0
C 18:1 n-9	21.8±0.0	23.4±0.2	23.0±0.2	22.8±0.1	20.7±0.0	22.7±0.1
C 18:1 n-7	2.6±0.0	2.7±0.1	2.5±0.0	2.9±0.0	2.9±0.1	2.8±0.0
C 20:1 n-9	1.2±0.1	1.4±0.0	1.2±0.1	5.0±0.2	4.8±0.0	4.9±0.1
C 22:1 n-11	0.0±0.0	0.0±0.0	0.0±0.0	4.4±0.2	4.2±0.0	4.1±0.0
C 22:1 n-9	0.2±0.0	0.2±0.0	0.2±0.0	0.7±0.0	0.6±0.0	0.6±0.0
C 24:1	1.2±0.0	1.2±0.0	1.1±0.0	0.6±0.0	0.6±0.0	0.6±0.0
ΣMUFA	32.1±0.1 ^f	34.4±0.1 ^d	33.0±0.0 ^c	41.8±0.2 ^a	39.1±0.0 ^c	41.1±0.0 ^b
PUFA						
C 18:2 n-6	4.3±0.0	4.4±0.0	4.5±0.0	6.7±0.0	6.1±0.0	6.8±0.0
C 18:3 n-3	2.8±0.0	2.7±0.1	2.8±0.0	2.7±0.0	2.3±0.0	2.7±0.0
C 18:4 n-3	1.9±0.0	1.7±0.0	1.8±0.0	1.3±0.1	1.4±0.0	1.4±0.0
C 20:2 n-6	0.9±0.0	0.9±0.0	0.9±0.0	0.7±0.0	0.7±0.0	0.7±0.0
C 20:3 n-6	0.1±0.0	0.1±0.0	0.1±0.0	0.2±0.0	0.2±0.0	0.2±0.0
C 20:3 n-3	0.4±0.0	0.4±0.0	0.4±0.0	0.3±0.0	0.3±0.0	0.3±0.0
C 20:4 n-6	0.6±0.0	0.6±0.0	0.6±0.0	0.6±0.0	0.8±0.0	0.7±0.0
C 20:4 n-3	2.0±0.0	1.8±0.0	2.0±0.0	1.3±0.0	1.5±0.0	1.4±0.0
C 20:5 n-3	6.6±0.1	5.9±0.0	6.4±0.1	7.5±0.0	8.6±0.2	7.8±0.0
C 22:5 n-3	3.1±0.0	2.7±0.0	3.2±0.0	3.5±0.1	3.9±0.0	3.7±0.0
C 22:6 n-3	18.0±0.2 ^a	15.1±0.1 ^b	17.7±0.2 ^a	8.9±0.1 ^c	10.3±0.1 ^c	9.1±0.0 ^d
ΣPUFA	40.7±0.2 ^a	36.3±0.0 ^b	40.4±0.1 ^a	33.7±0.1 ^e	36.1±0.0 ^c	34.8±0.0 ^d
EPA+DHA	24.6±0.1 ^a	21.0±0.0 ^c	24.1±0.1 ^b	16.4±0.0 ^f	18.9±0.1 ^d	16.9±0.0 ^c

450 Results are expressed as means of six measurements ± SD. The values in the rows marked with
 451 different letters (a - c) differ significantly (p<0.05).

453 Table 4. Characteristics of the oils isolated from salmon byproducts using three different
 454 procedures of extraction.

Procedure of extraction	Type of byproducts	Yield [%]	PV [mEqO ₂ /kg]	AV [mgKOH/g]	Phospholipids [% of total lipids]
I	Heads	71.1±0.4 ^c	9.2±0.6 ^a	1.34±0.03 ^a	0.02±0.00 ^d
	Heads	71.5±1.1 ^c	2.5±0.2 ^b	0.18±0.01 ^c	0.15±0.01 ^c
II	Skins	95.2±2.2 ^a	0.8±0.1 ^d	0.43±0.01 ^{cd}	0.13±0.01 ^c
	Backbones	82.7±1.7 ^b	0.7±0.1 ^d	0.85±0.02 ^b	0.29±0.06 ^b
III	Heads	72.1±0.9 ^c	1.6±0.1 ^c	0.70±0.02 ^c	1.47±0.11 ^a

455 Results are expressed as means of six measurements ± SD. The values in the columns marked with
 456 different letters (a - c) differ significantly (p<0.05).

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458 Table 5. Fatty acid composition (% of the total fatty acids) of oils isolated from salmon
 459 byproducts using three different procedures of extraction

Fatty acid	Procedure of extraction				
	I heads	heads	II skins	backbones	III heads
SAFA					
C 14:0	4.1±0.1	4.1±0.2	4.1±0.2	4.0±0.0	4.6±0.1
C 15:0	0.3±0.0	0.3±0.0	0.3±0.0	0.3±0.0	0.3±0.0
C 16:0	11.7±0.2	11.6±0.2	11.4±0.5	11.2±0.0	12.2±0.1
C 17:0	0.5±0.0	0.5±0.0	0.5±0.0	0.5±0.0	0.5±0.0
C 18:0	2.6±0.1	2.6±0.1	2.5±0.0	2.5±0.0	2.6±0.0
C 20:0	0.5±0.0	0.5±0.0	0.5±0.0	0.5±0.0	0.5±0.0
ΣSAFA	19.7±0.2 ^b	19.6±0.2 ^b	19.3±0.4 ^{bc}	19.0±0.0 ^c	20.7±0.1 ^a
MUFA					
C 14:1	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0
C 16:1	0.2±0.0	0.2±0.0	0.2±0.0	0.2±0.0	0.2±0.0
C 16:1 n-7	5.0±0.1	4.4±0.1	4.7±0.3	4.7±0.0	5.1±0.1
C 17:1	0.4±0.0	0.4±0.0	0.4±0.0	0.4±0.0	0.4±0.0
C 18:1 n-9	21.4±0.2	23.9±0.2	23.4±0.6	23.1±0.2	21.7±0.3
C 18:1 n-7	3.0±0.1	2.8±0.0	2.9±0.1	2.7±0.1	3.0±0.1
C 20:1 n-9	4.6±0.1	5.0±0.1	5.0±0.1	5.3±0.3	4.6±0.1
C 22:1 n-11	4.0±0.0	4.4±0.1	4.2±0.1	4.5±0.0	3.9±0.1
C 22:1 n-9	0.6±0.0	0.7±0.0	0.7±0.0	0.7±0.0	0.6±0.0
C 24:1	0.6±0.0	0.6±0.0	0.6±0.0	0.6±0.0	0.5±0.0
ΣMUFA	39.9±0.2 ^b	42.5±0.2 ^a	42.2±0.5 ^a	42.3±0.2 ^a	40.1±0.2 ^b
PUFA					
C 18:2 n-6	6.4±0.1	7.2±0.0	7.1±0.2	6.8±0.0	6.4±0.2
C 18:3 n-3	2.4±0.1	2.9±0.0	2.8±0.2	2.7±0.0	2.5±0.1
C 18:4 n-3	1.4±0.0	1.3±0.0	1.4±0.0	1.4±0.0	1.4±0.0
C 20:2 n-6	0.7±0.0	0.7±0.0	0.7±0.0	0.7±0.0	0.7±0.0
C 20:3 n-6	0.2±0.0	0.2±0.0	0.2±0.0	0.2±0.0	0.2±0.0
C 20:3 n-3	0.3±0.0	0.3±0.0	0.3±0.0	0.3±0.0	0.3±0.0
C 20:4 n-6	0.7±0.0	0.6±0.0	0.6±0.0	0.6±0.0	0.6±0.0
C 20:4 n-3	1.4±0.0	1.3±0.0	1.4±0.1	1.4±0.0	1.4±0.0
C 20:5 n-3	8.3±0.2	7.1±0.1	7.3±0.4	7.4±0.0	8.0±0.2
C 22:5 n-3	3.6±0.0	3.1±0.0	3.4±0.5	3.4±0.0	3.4±0.1
C 22:6 n-3	9.1±0.2	8.0±0.1	8.1±0.3	8.3±0.0	8.7±0.2
ΣPUFA	34.5±0.2 ^a	32.7±0.1 ^c	33.3±0.5 ^{bc}	33.2±0.0 ^{bc}	33.6±0.2 ^b
EPA+DHA	17.4±0.2 ^a	15.1±0.1 ^d	15.4±0.3 ^{cd}	15.7±0.0 ^c	16.7±0.2 ^b

460 Results are expressed as means of six measurements ± SD. The values in the rows marked with
 *51 different letters (a - c) differ significantly (p<0.05).