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Effect of boiling and frying on the content of essential polyunsaturated fatty acids in muscle tissue of four fish species

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Abstract

Frozen samples of common fish species, sea trout (*Salmo trutta*), from Norway and Siberia, herring (*Clupea harengus pallasi*), rock sole (*Lepidopsetta bilineata*) and cod (*Gadus morhua maris-albi*), collected from a wholesale market in Krasnoyarsk city (Siberia, Russia) were analyzed. Special attention was paid to long-chain essential polyunsaturated fatty acids: eicosapentaenoic, 20:5ω3 (EPA) and docosahexaenoic, 22:6ω3 (DHA). Heat-treatment (cooking and frying) did not in general significantly decrease the contents of EPA and DHA compared to raw fish species, except for a modest reduction in Norwegian trout during frying. Boiled trout appeared to be a more valuable fish dish for obtaining the officially recommended appropriate daily intake of EPA + DHA for humans. Herring and sole had intermediate values, while boiled cod had a comparatively low value.

Keywords: Essential polyunsaturated fatty acids; Trout; Herring; Sole; Cod

1. Introduction

Recently, diverse benefits for human health, due to the consumption of polyunsaturated fatty acids (PUFA), especially eicosapentaenoic (20:5ω3, EPA) and docosahexaenoic (22:2ω3, DHA) have been widely recognized (e.g., Arts, Ackman, & Holub, 2001; Broadhurst et al., 2002; Lauritzen, Hansen, Jorgensen, & Michaelsen, 2001; Silvers & Scott, 2002). Since only some microalgae species are effective producers of EPA and DHA, aquatic ecosystems are the principal source of the two essential PUFAs in the biosphere, and humans obtain these acids through fish and other marine and freshwater products (Arts et al., 2001). Fish species, from different ecosystems, are known to differ in their FA composition; therefore, studies of PUFA contents of diverse fish from various locations are of great importance for revealing their potential value as sources of the essential ω3 acids for human nutrition (Ahlgren, Blomqvist, Boberg, & Gustafsson, 1994; Celik, Diler, & Kucukgulmez, 2005; Gokce, Tasbozan, Celik, & Tabakoglu, 2004; Ozyurt, Polat, & Ozkutuk, 2005; Rasoarahona, Barnathan, Bianchini, & Gaydou, 2005; Vaccaro, Buffa, Messina, Santulli, & Mazzola, 2005; Varljen, Baticic, Sincic-Modric, Varljen, & Kapovic, 2005).

Meanwhile, the consumption of raw fish is rare in Western society and information about PUFA contents of raw fish may have limited value for a conclusion on their food quality (Candela, Astiasaran, & Bello, 1998). Indeed, the long-chain polyunsaturated acids, such as EPA and DHA, are considered to be especially susceptible to oxidation during heating and other culinary treatments (Candela et al., 1998; Ohshima, Shozen, Usio, & Koizumi, 1996; Sampaio, Bastos, Soares, Queiroz, & Torres, 2006; Sant'Ana & Mancini-Filho, 2000; Tarley, Visentainer, Matsushita, & de Souza, 2004). Nevertheless, it was found that the EPA and DHA levels remained unchanged in some

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fish species in certain types of cooking (Candela et al., 1998; Echarte, Zulet, & Astiasaran, 2001; Gladyshev, Sushchik, Gubanenko, Demirchieva, & Kalachova, 2006; Stolyhwo, Kolodziejska, & Sikorski, 2006). Therefore, the aim of our work was to study the possible influence of two ways of treatment, frying and boiling, on PUFA contents in several fish species common in Siberian markets.

2. Materials and methods

2.1. Fish samples

Commercially available frozen fish were collected at a local wholesale market at the same time in Krasnoyarsk city (Siberia, Russia). Reputable and large Krasnoyarsk firms were chosen as the providers to be sure, that all the Federal Standards of storage of fish were followed before selling. The fish were held at the market prior to being sampled during about three days, at −6 to −8 °C. The fish species were as follows: sea trout, *Salmo trutta* Linne, from Norwegian and Siberian (Yenisei river at Mainskaya dam) aquacultures, designated below as trout N and trout S, respectively. Herring, *Clupea harengus pallasi* (Cuvier et Valenciennes) and rock sole, *Lepidopsetta bilineata* (Ayres) were both caught in the far east of Russia. Cod, *Gadus morhua maris-albi* (Derjugin) was caught in the White Sea in the north west of Russia. Fish, collected from the market, were held in frozen storage cabinets below −20 °C before the following treatment: three fishes of each species were used in each analysis, i.e., were sampled under each treatment: control (raw), boiling and frying. Fried cod was not analyzed because of a technical incident. Therefore, 42 samples from 42 fishes were analyzed. Muscle tissues (fillets) below the dorsal fin were taken as the samples. The tissues of raw fish were thawed at room temperature during about one hour prior to analyses. The cooked fish were sampled for the following analyses within in one hour after the cooking. All skin was removed from the muscle tissue prior to analyses.

2.2. Heat-treatments

Common ways of heat-treatment were used: boiling at 85–90 °C during 10–15 min and frying in sunflower oil at 150–170 °C during 15–20 min. The cooking times could not be standardized to one precise time interval because of different sizes of portion slices of fish. Sunflower oil was used because it is the most common cooking oil in Russia.

2.3. Analysis

To measure moisture content, fillets from the same fish samples of about 10–15 g of wet weight were taken and dried to constant weight at 105 °C. Lipid extraction and pre-treatment, and chromato-mass-spectrometry of methyl esters of fatty acids were the same as in our previous work (Gladyshev et al., 2006).

2.4. Statistics

Calculations of standard errors (SE), Student's *t*-test and two-way ANOVA were carried out in the conventional way (Campell, 1967). One-linkage cluster analysis was carried out conventionally (Jeffers, 1981), using Euclidean distances. Prominent fatty acid contents (g/100 g of dry weight) were used as the axes of multidimensional hyperspace. Calculations were carried out using STATISTICA software, version 6.0 (StatSoft Inc., Tulsa, OK, USA).

3. Results

The moisture content varied in all fish samples from about 61% to 80% (Table 1). Higher moisture contents were characteristic of cod, and lower contents were found for Norwegian trout. An explicit tendency to decrease of moisture contents in all fish species due to frying occurred (Table 1).

In all samples, 82 fatty acids (FA) were identified. Quantitatively prominent FAs are listed in Tables 2–4. The levels of the two essential PUFAs, EPA and DHA (per cent of total FAs), in fish species were different. The lowest level of EPA was characteristic of trout, 5.9 –7.0% (calculated from Table 2), while sole had the highest level, up to 22.3% (calculated from Table 4), and herring and cod had intermediate levels, on average 10.2% and 14.6%, respectively (calculated from Tables 3 and 4). In contrast, the highest level of DHA was characteristic of cod (on average 37.8%, calculated from Table 4) while trout and herring had intermediate levels (16.7–28.5%, calculated from Tables 2 and 3) and sole had the lowest level (on average 11.2%, calculated from Table 4).

Cluster analysis revealed no explicit effect of the way of cooking on the overall FA composition of fish compared with control (Fig. 1). The most constant and peculiar FA composition was characteristic of cod, boiled and raw, whose samples were joined into one separate cluster (Fig. 1). Eight of nine samples of sole, cooked and raw, also formed a separate cluster. Herring and both kinds of trout, Siberian and Norwegian, had more or less comparable FA compositions, although some samples of trout N also formed small clusters (Fig. 1). Therefore, overall FA composition depended primarily on fish species, rather than way of cooking.

Table 1
Moisture content (%) in raw and cooked fish: mean values from three samples ± SE (standard error)

Species	Raw	Boiled	Fried
Trout N (Norway)	64.1 ± 1.0	64.6 ± 0.1	61.3 ± 0.7
Trout S (Siberia)	73.6 ± 0.2	68.3 ± 4.0	65.9 ± 0.3
Herring	73.9 ± 1.8	70.7 ± 1.6	71.2 ± 0.9
Sole	75.7 ± 1.1	73.0 ± 0.1	70.4 ± 1.0
Cod	79.8 ± 0.2	76.3 ± 0.8	nd

nd – no data.

Table 2
Prominent fatty acid contents (g/100 g of dry weight) in trout after different types of heat-treatment: mean values from three samples ± SE

Fatty acids	Trout N (Norway)			Trout S (Siberia)		
	Control (raw)	Boiled	Fried	Control (raw)	Boiled	Fried
14:0	0.311 ± 0.068	0.224 ± 0.044	0.154 ± 0.082	0.209 ± 0.057	0.198 ± 0.040	0.091 ± 0.009
15:0	0.037 ± 0.010	0.023 ± 0.009	0.015 ± 0.009	0.036 ± 0.009	0.033 ± 0.008	0.012 ± 0.002
16:0	1.031 ± 0.147	0.935 ± 0.085	0.593 ± 0.158	0.883 ± 0.134	0.964 ± 0.146	0.645 ± 0.033
16:1ω7	0.293 ± 0.068	0.223 ± 0.026	0.132 ± 0.055	0.220 ± 0.058	0.254 ± 0.042	0.117 ± 0.021
17:0	0.041 ± 0.010	0.019 ± 0.006	0.013 ± 0.008	0.038 ± 0.008	0.038 ± 0.008	0.006 ± 0.000
16:2ω4	0.025 ± 0.007	0.013 ± 0.003	0.009 ± 0.006	0.011 ± 0.003	0.012 ± 0.003	0.004 ± 0.000
6:3ω4	0.020 ± 0.004	0.012 ± 0.003	0.008 ± 0.006	0.006 ± 0.002	0.003 ± 0.001	0.004 ± 0.000
16:4ω1	0.030 ± 0.005	0.014 ± 0.005	0.012 ± 0.008	0.008 ± 0.001	0.008 ± 0.002	0.002 ± 0.001
18:0	0.170 ± 0.051	0.299 ± 0.149	0.162 ± 0.103	0.173 ± 0.047	0.217 ± 0.058	0.263 ± 0.025
18:1ω9	1.227 ± 0.165	1.231 ± 0.083	0.668 ± 0.159	0.599 ± 0.137	0.763 ± 0.132	0.422 ± 0.043
18:1ω7	0.182 ± 0.020	0.095 ± 0.016	0.021 ± 0.021	0.091 ± 0.013	0.106 ± 0.011	
18:2ω6	0.347 ± 0.080	0.366 ± 0.029	0.274 ± 0.083	0.218 ± 0.056	0.318 ± 0.064	0.317 ± 0.020
18:3ω6	0.016 ± 0.009	0.001 ± 0.001	tr	0.006 ± 0.002	0.008 ± 0.003	tr
18:3ω3	0.136 ± 0.048	0.156 ± 0.009	0.090 ± 0.031	0.064 ± 0.016	0.094 ± 0.016	0.052 ± 0.013
18:4ω3	0.073 ± 0.033	0.063 ± 0.006	0.045 ± 0.020	0.063 ± 0.017	0.076 ± 0.015	0.057 ± 0.027
20:1ω11 + ω9	0.260 ± 0.046	0.288 ± 0.026	0.144 ± 0.052	0.225 ± 0.060	0.305 ± 0.066	0.137 ± 0.033
20:2ω6	0.025 ± 0.008	0.021 ± 0.003	0.010 ± 0.003	0.019 ± 0.005	0.023 ± 0.004	0.008 ± 0.001
20:3ω6	0.009 ± 0.002	0.007 ± 0.001	0.004 ± 0.001	0.007 ± 0.001	0.009 ± 0.002	0.002 ± 0.000
20:4ω6	0.037 ± 0.004	0.037 ± 0.002	0.023 ± 0.004	0.032 ± 0.004	0.036 ± 0.004	0.025 ± 0.003
20:3ω3	0.012 ± 0.003	0.010 ± 0.001	0.005 ± 0.001	0.007 ± 0.002	0.009 ± 0.001	0.003 ± 0.000
20:4ω3	0.066 ± 0.011	0.065 ± 0.005	0.039 ± 0.011	0.053 ± 0.012	0.067 ± 0.009	0.034 ± 0.005
20:5ω3	0.376 ± 0.046	0.396 ± 0.034	0.253 ± 0.046	0.279 ± 0.046	0.361 ± 0.039	0.246 ± 0.019
22:1ω11 + ω9	0.195 ± 0.033	0.285 ± 0.027	0.119 ± 0.039	0.172 ± 0.052	0.256 ± 0.060	0.097 ± 0.025
22:4ω6	0.022 ± 0.002	0.014 ± 0.007	0.014 ± 0.004	0.012 ± 0.003	0.016 ± 0.003	0.001 ± 0.001
22:5ω6	0.005 ± 0.003	0.007 ± 0.002	0.003 ± 0.001	0.004 ± 0.000	0.003 ± 0.002	0.010 ± 0.004
22:4ω3	0.015 ± 0.001	0.015 ± 0.003	0.008 ± 0.002	0.014 ± 0.002	0.014 ± 0.001	0.013 ± 0.003
22:5ω3	0.144 ± 0.020	0.151 ± 0.016	0.086 ± 0.015	0.079 ± 0.014	0.115 ± 0.015	0.059 ± 0.004
22:6ω3	1.03 ± 0.033	1.23 ± 0.179	0.718 ± 0.039	1.18 ± 0.097	1.41 ± 0.127	1.045 ± 0.223
Total FA	6.13 ± 0.868	6.20 ± 0.378	3.62 ± 0.940	4.71 ± 0.854	5.72 ± 0.839	3.67 ± 0.343
Total ω3	1.67 ± 0.086	1.72 ± 0.119	1.29 ± 0.106	1.83 ± 0.117	1.97 ± 0.032	1.69 ± 0.269
Total ω6	0.396 ± 0.051	0.412 ± 0.018	0.302 ± 0.051	0.253 ± 0.036	0.359 ± 0.040	0.339 ± 0.012
ω3/ω6	4.81 ± 1.42	4.26 ± 0.733	5.24 ± 2.02	7.82 ± 1.20	5.88 ± 1.09	4.86 ± 1.02

tr – traces.

To reveal a possible effect of the way of cooking on the contents of the two essential PUFAs, EPA and DHA, a two-way ANOVA was carried out. As found (Table 5), the contents of the two PUFAs significantly depended on fish species only, while the influence of the way of cooking was comparatively very low and statistically insignificant. Therefore, the results of ANOVA for the two acids were in a good agreement with results of the cluster analysis for all quantitatively prominent FAs.

To detail the general results of ANOVA, significance of differences between mean values (Fig. 2) were calculated using the Student's *t*-test. Statistically significant differences ($p < 0.05$, d.f. = 4) were found between raw trout N and raw cod ($t = 3.58$), boiled trout N and boiled cod ($t = 2.81$), boiled trout S and boiled cod ($t = 4.41$) and between boiled herring and boiled cod ($t = 3.58$). Thus, boiled cod had a significantly lower EPA + DHA content than had the other fish species, except sole. There were no significant differences in the two PUFA contents between fried fish species. Cooking, namely frying, significantly affected EPA + DHA content in Norwegian trout only (Fig. 2): differences between raw trout N and fried trout N, and between boiled trout N and fried trout N were statistically significant ($t = 4.41$ and $t = 2.93$, respectively). For all the other species, there were no significant differences between raw and cooked samples in the contents of the two essential PUFAs (Fig. 2).

Using data of Tables 1–4, the quantities of food, which can provide the officially recommended appropriate intake of EPA + DHA for humans, about 1 g per day (e.g., Ahlgren et al., 1994; Arts et al., 2001), were calculated (Table 6). As found, boiled trout was the most valuable food as the essential PUFAs' source, while boiled cod had a comparatively low nutritive value.

4. Discussion

In general, heat-treatment of the raw fish species did not cause a significant decrease in the EPA + DHA content, except for Norwegian trout. We do not know, whether the freezing and storage affected FA contents in the fish species, but we can compare the two essential PUFA levels in the raw fish with literature data on some fresh fish species. In common sole (*Solea solea*), the content of EPA was

Table 3
Prominent fatty acid contents (g/100 g of dry weight) in herring after different types of heat-treatment: mean values from 3 samples ± SE

Fatty acids	Control (raw)	Boiled	Fried
14:0	0.310 ± 0.094	0.483 ± 0.009	0.206 ± 0.036
15:0	0.026 ± 0.006	0.029 ± 0.002	0.012 ± 0.001
16:0	0.912 ± 0.160	0.874 ± 0.033	0.673 ± 0.006
16:1ω7	0.303 ± 0.093	0.400 ± 0.021	0.221 ± 0.013
17:0	0.043 ± 0.013	0.040 ± 0.000	0.022 ± 0.005
16:2ω4	0.014 ± 0.005	0.016 ± 0.000	0.006 ± 0.001
16:3ω4	0.006 ± 0.002	0.009 ± 0.000	0.003 ± 0.001
16:4ω1	0.016 ± 0.006	0.022 ± 0.001	0.009 ± 0.001
18:0	0.083 ± 0.020	0.061 ± 0.025	0.059 ± 0.002
18:1ω9	0.719 ± 0.334	0.693 ± 0.043	0.433 ± 0.038
18:1ω7	0.180 ± 0.053	0.155 ± 0.000	0.102 ± 0.012
18:2ω6	0.047 ± 0.018	0.031 ± 0.020	0.090 ± 0.018
18:3ω6	0.004 ± 0.001	0.008 ± 0.000	0.001 ± 0.000
18:3ω3	0.025 ± 0.011	0.010 ± 0.013	0.009 ± 0.000
18:4ω3	0.073 ± 0.035	0.062 ± 0.027	0.040 ± 0.006
20:1ω11 + ω9	0.424 ± 0.251	0.248 ± 0.033	0.221 ± 0.025
20:2ω6	0.011 ± 0.004	0.008 ± 0.001	0.002 ± 0.001
20:3ω6	0.004 ± 0.001	0.004 ± 0.000	0.001 ± 0.001
20:4ω6	0.029 ± 0.006	0.017 ± 0.003	0.017 ± 0.002
20:3ω3	0.005 ± 0.002	0.002 ± 0.000	0.001 ± 0.001
20:4ω3	0.032 ± 0.013	0.031 ± 0.005	0.022 ± 0.004
20:5ω3	0.562 ± 0.140	0.481 ± 0.019	0.399 ± 0.057
22:1ω11 + ω9	0.441 ± 0.269	0.316 ± 0.025	0.241 ± 0.038
22:4ω6	0.018 ± 0.005	0.015 ± 0.001	0.010 ± 0.001
22:5ω6	0.004 ± 0.004	0.004 ± 0.004	tr
22:4ω3	0.006 ± 0.001	0.004 ± 0.003	0.003 ± 0.000
22:5ω3	0.031 ± 0.012	0.029 ± 0.004	0.020 ± 0.003
22:6ω3	1.23 ± 0.219	0.866 ± 0.223	0.918 ± 0.188
Total FA	5.57 ± 1.749	4.93 ± 0.343	3.74 ± 0.319
Total ω3	1.27 ± 0.135	0.898 ± 0.269	0.941 ± 0.108
Total ω6	0.075 ± 0.016	0.055 ± 0.012	0.101 ± 0.012
ω3/ω6	19.7 ± 4.34	21.1 ± 1.02	9.39 ± 0.749

about 4% and DHA about 19% (Gokce et al., 2004), i.e., the sum level of these acids was comparable to that in raw rock sole, *L. bilineata*, studied in our work (calculated from Table 4). The proportions of EPA and DHA (% of total FA) in larval Atlantic cod (*Gadus morhua*), depending on diet, were 3.7–12.8 and 24.6–32.1, respectively (Bransden, Butterfield, Walden, McEvoy, & Bell, 2005), and were in a good agreement with our data on the raw cod (calculated from Table 4). Gilthead sea bream (*Sparus aurata*) and White Sea bream (*Diplodus sargus*) had EPA and DHA levels 4–7% and 7–20%, respectively (Ozyurt et al., 2005), which were comparable with our data on raw fish (calculated from Tables 2–4), while two-banded sea bream, *Diplodus vulgaris*, had somewhat lower levels in muscle tissue: 1–5% of EPA and 1–10% of DHA (Varljen et al., 2005). In three species of tilapia from Madagascar, the contents of EPA and DHA in fresh samples were slightly lower than our data for raw fish: 1–3% and 4–11% (Rasoarahona et al., 2005). Dorsal muscle samples of fresh sturgeon hybrid (*Acipenser naccarii* × *A. baerii*) had 9% of EPA and 15% of DHA (Vaccaro et al., 2005). Raw fillets of zander (*Sander lucioperca*) had EPA and DHA levels about 3–4% and 7–12%, respectively (Celik et al., 2005). Thus, on the basis of the above indirect comparison, freezing and storage, in general, seem to provide no significant effect on EPA and DHA levels compared with that of fresh fish. Moreover, when a direct study of the influence of freezing and storage on contents of the two essential PUFAs in Atlantic mackerel (*Scomber scombrus*) and in Baltic sprats (*Sprattus sprattus*) was carried out, no significant effect was revealed (Stolyhwo et al., 2006).

In any case, cooked fish species, studied in our work, had high contents of the two essential PUFAs. Even in fried Norwegian trout, in which PUFAs were found to be significantly decreased compared to the raw fish, the EPA + DHA content was not significantly lower than that in the other fried fish species (Fig. 2). Although many authors estimate potential nutritive value of fish on the basis of per cent content of PUFA, it would be better to draw such conclusions using mass units, e.g., quantity of EPA + DHA in a fish dish, or, in other words, the quantity of fish dish to be consumed by an individual to obtain the daily quantity of the two essential PUFAs recommended by WHO. Estimations of fish nutritive value, based on mass units are comparatively scarce. For fried salmon, mackerel and sardines, the EPA + DHA contents were 1.7, 0.39 and 0.88 g/100 g of food, respectively (Candela et al., 1998). Thus, to obtain 1 g of EPA + DHA per day, it is necessary to consume ~59 g of fried salmon, 256 g of fried mackerel, or 114 g of fried sardines. These figures are comparable to those, obtained in our present work (Table 6). Meanwhile, fried salmon (Candela et al., 1998) appears to be the most valuable food for EPA + DHA intake, while boiled cod (Table 6) has a comparatively low value.

Boiling was found to be the more suitable treatment, because boiled fish had a comparatively higher nutritive value (from the PUFAs' intake), than had fried fish (Table 6). These results are in a good agreement with those in our previous study, where it was demonstrated that the daily required quantity of the two essential ω3 PUFAs was contained in 167 g of boiled humpback salmon (*Oncorhynchus gorbuscha*), but in 233 g of fried humpback (Gladyshev et al., 2006).

It should be emphasized, that a comparison of EPA + DHA contents in raw fish tissues may not provide explicit information on the nutritive value of these species after cooking. Indeed, in our study, raw Norwegian trout and Siberian trout had practically equal quantities of these two acids, while in fried Norwegian trout the essential PUFA content was significantly lower than that in Siberian trout (Fig. 2). Therefore, conclusions on nutritive value of fish species, based on data from fresh fish samples, should be made with caution. Moreover, comparison of per cent levels of essential PUFAs may result in a misleading notion concerning the nutritive value. Indeed, in our study, cod had the highest levels of EPA + DHA, ~52% (calculated from Table 4), while trout had only 26% (calculated from Table 2). Nevertheless, as cooked fish, trout appeared to be the best food for providing humans with officially

Table 4
Prominent fatty acid contents (g/100 g of dry weight) in sole and cod after different types of heat-treatment: mean values from three samples ± SE

Fatty acids	Sole			Cod	
	Control (raw)	Boiled	Fried	Control (raw)	Boiled
14:0	0.109 ± 0.030	0.115 ± 0.015	0.084 ± 0.015	0.022 ± 0.003	0.011 ± 0.004
15:0	0.027 ± 0.004	0.018 ± 0.004	0.013 ± 0.001	0.004 ± 0.001	0.002 ± 0.001
16:0	0.595 ± 0.050	0.616 ± 0.052	0.528 ± 0.032	0.451 ± 0.026	0.366 ± 0.019
16:1ω7	0.313 ± 0.104	0.451 ± 0.106	0.279 ± 0.072	0.028 ± 0.005	0.018 ± 0.001
17:0	0.054 ± 0.007	0.018 ± 0.008	0.026 ± 0.002	0.013 ± 0.005	0.011 ± 0.000
16:2ω4	0.018 ± 0.007	0.033 ± 0.009	0.020 ± 0.009	0.001 ± 0.001	tr
16:3ω4	0.016 ± 0.005	0.045 ± 0.011	0.019 ± 0.009	0.001 ± 0.000	tr
16:4ω1	0.028 ± 0.010	0.063 ± 0.018	0.040 ± 0.020	0.000 ± 0.000	0.000 ± 0.000
18:0	0.112 ± 0.011	0.194 ± 0.012	0.127 ± 0.006	0.088 ± 0.010	0.072 ± 0.006
18:1ω9	0.338 ± 0.114	0.490 ± 0.152	0.357 ± 0.063	0.163 ± 0.015	0.211 ± 0.013
18:1ω7	0.158 ± 0.029	0.027 ± 0.027	0.121 ± 0.020	0.076 ± 0.004	0.021 ± 0.010
18:2ω6	0.021 ± 0.006	0.028 ± 0.006	0.231 ± 0.058	0.008 ± 0.003	0.005 ± 0.001
18:3ω6	0.006 ± 0.003	tr	0.005 ± 0.001	0.000 ± 0.000	0.000 ± 0.000
18:3ω3	0.003 ± 0.001	tr	0.006 ± 0.001	0.003 ± 0.001	tr
18:4ω3	0.046 ± 0.021	0.071 ± 0.026	0.043 ± 0.020	0.007 ± 0.002	0.004 ± 0.001
20:1ω11	0.076 ± 0.017	0.149 ± 0.039	0.046 ± 0.006	0.032 ± 0.002	0.045 ± 0.005
20:1ω9	0.029 ± 0.015	0.018 ± 0.018	0.023 ± 0.003	0.001 ± 0.001	tr
20:2ω6	0.026 ± 0.017	0.005 ± 0.002	0.013 ± 0.008	0.003 ± 0.001	0.002 ± 0.000
20:3ω6	0.005 ± 0.000	0.001 ± 0.001	0.013 ± 0.010	0.001 ± 0.000	0.001 ± 0.000
20:4ω6	0.085 ± 0.004	0.060 ± 0.005	0.070 ± 0.001	0.029 ± 0.001	0.031 ± 0.003
20:3ω3	0.064 ± 0.061	0.005 ± 0.003	0.002 ± 0.001	0.001 ± 0.000	0.001 ± 0.000
20:4ω3	0.016 ± 0.005	0.004 ± 0.002	0.012 ± 0.003	0.005 ± 0.001	0.006 ± 0.001
20:5ω3	0.719 ± 0.083	0.879 ± 0.269	0.676 ± 0.153	0.313 ± 0.028	0.267 ± 0.023
22:1ω11	0.025 ± 0.004	0.016 ± 0.008	0.019 ± 0.003	0.010 ± 0.001	0.018 ± 0.003
22:1ω9	0.009 ± 0.001	tr	tr	tr	0.001 ± 0.001
22:4ω6	0.040 ± 0.009	0.040 ± 0.010	0.019 ± 0.007	0.009 ± 0.003	0.009 ± 0.001
22:5ω6	0.015 ± 0.002	0.009 ± 0.003	0.007 ± 0.002	0.001 ± 0.001	0.002 ± 0.000
22:4ω3	0.026 ± 0.001	0.025 ± 0.003	0.021 ± 0.001	0.006 ± 0.001	0.011 ± 0.000
22:5ω3	0.119 ± 0.006	0.124 ± 0.034	0.101 ± 0.017	0.038 ± 0.004	0.042 ± 0.002
22:6ω3	0.459 ± 0.060	0.437 ± 0.085	0.373 ± 0.051	0.757 ± 0.043	0.743 ± 0.049
Total FA	3.56 ± 0.608	3.94 ± 0.769	3.29 ± 0.520	2.07 ± 0.042	1.90 ± 0.057
Total ω3	0.798 ± 0.053	0.561 ± 0.119	0.479 ± 0.067	0.798 ± 0.046	0.785 ± 0.047
Total ω6	0.084 ± 0.018	0.073 ± 0.017	0.267 ± 0.050	0.020 ± 0.004	0.019 ± 0.000
ω3/ω6	9.97 ± 1.24	7.92 ± 0.747	1.87 ± 0.283	43.7 ± 9.84	41.3 ± 3.27

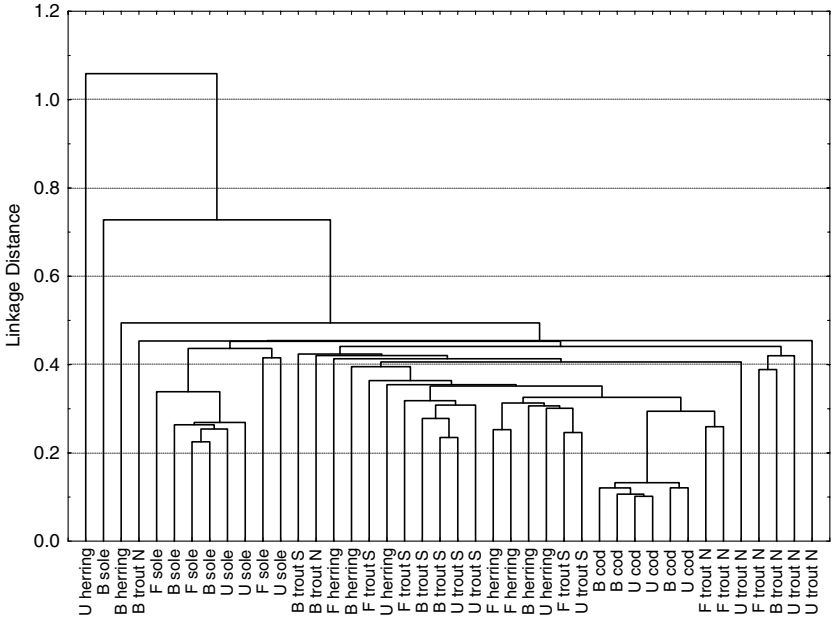

Fig. 1. Dendrogram of the cluster analysis of the contents (g/100 g of dry weight) of 28 prominent fatty acids (see Tables 2–4) in fish samples: U – raw, B – boiled, F – fried; for trout, N and S mean Norwegian and Siberian, respectively. The ordinate axis represents Euclidean distances in 28-dimension hyperspace.

Table 5
Results of two-way ANOVA comparing sum of eicosapentaenoic and docosahexaenoic fatty acid contents (EPA + DHA, g/100 g of dry weight) in raw and cooked fish

Source of variation (independent variables)	Sum of squares	Variance explained (%)	d.f.	*F*	*p*
A: species	1.208	20.3	3	**3.22**	<0.05
B: way of cooking	0.504	8.5	2	2.69	>0.05
AB: interaction	1.057	17.7	6	1.41	>0.05

Between levels degree of freedom d.f. = 36. Significant value of Fisher's *F*-test is given in bold.

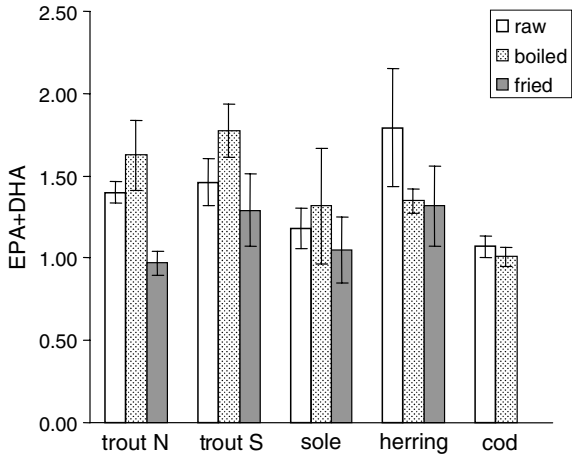

Fig. 2. Sum of eicosapentaenoic and docosahexaenoic fatty acid contents (g/100 g of dry weight) in raw and cooked fish: mean values from 3 samples. Bars represent standard errors. For trout, N and S mean Norwegian and Siberian, respectively.

Table 6
Quantity of product (g) which can provide a human with the recommended daily quantity of sum of eicosapentaenoic and docosahexaenoic fatty acids of 1 g

Species	Boiled	Fried
Trout N	174	266
Trout S	178	227
Herring	253	264
Sole	281	322
Cod	418	

recommended appropriate daily intakes of EPA + DHA, while cod had a comparatively low value (Table 6).

5. Conclusions

The percentages of the two essential PUFAs in the fish species studied were comparable to those reported for fresh samples of the different fish species from diverse locations. Heat-treatment (cooking and frying), in general, did not significantly decrease the contents of EPA and DHA in four fish species, except for a modest reduction in Norwegian trout during frying. Boiled trout appeared to be a more valuable fish dish for obtaining officially recommended appropriate daily intakes of EPA + DHA for humans; herring and sole had intermediate values, while boiled cod had a comparatively low value. A comparison of EPA + DHA contents in raw fish species, especially as per cent levels only, may not provide explicit information about the nutritive value of these species after cooking.

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