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Determination of Nutrient, Fatty Acid, Micro, and Macronutrient Content of Frozen Freshwater Fish

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ABSTRACT

Understanding the nutritional composition of foods is essential for healthy choices and sustainable consumption. Although frozen fish are often perceived as nutritionally inferior to fresh fish, research has not determined whether freezing actually reduces their nutrient content or overall quality. To characterize the nutrient, fatty acid, and mineral profiles of commonly consumed frozen freshwater species, we analyzed samples from four species. Results demonstrated that commercially available frozen products had nutrient levels comparable to those reported in the literature for unfrozen fish. Among the species, carp showed the highest protein (83.01 ± 0.5%), followed by silver carp (71.97 ± 1.6 %), whereas African catfish (22.75 ± 0.1 %) and grass carp (20.28 ± 0.1 %) had the highest fat. Notably, carp skin protein (75.30 ± 0.3 %) exceeded fillet, and trout skin fat (38.45 ± 0.1 %) surpassed its fillet. Grass carp recorded the highest SFA (42.50 ± 0.1 %), PUFA (41.63 ± 0.1 %), and UFA (86.64 ± 0.1 %; ratio 0.98). Carp fillet had the highest MUFA (58.70 ± 0.3 %), while trout fillet showed elevated n-6 (28.31 ± 0.0 %) and n-3 (12.35 ± 0.0 %). Mineral profiles varied: carp was richest in Fe, Zn, Cu, Mg, Na; silver carp in Mn, Ca, P; trout in K. Taken together, frozen freshwater fish remain excellent sources of essential polyunsaturated fatty acids and micro- and macroelements, matching fresh fish quality.

Keywords: freshwater fish, nutritional composition, fatty acid composition, microelements, macroelements

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1. INTRODUCTION

Fish consumption accounts for about 20 % of the world's animal protein intake and, in some countries, can reach 50 % (FAO, 2021). The growing population and shifting dietary habits are driving increased demand for fish as a source of protein and healthy fats (FAO, 2020). Global seafood consumption, particularly fish, is projected to rise 15 % by 2030, reaching an average of 21.4 kg per person (FAO, 2022). Despite this global trend, Hungary remains a modest consumer, with per capita fish intake well below European and world averages. The sustainability of this vital resource is increasingly threatened by overfishing, habitat destruction, and climate change, resulting in the decline of many fisheries (Edgar et al., 2024). Currently, about 35 % of fisheries are overfished, leaving few opportunities for further expansion (FAO, 2022).

Understanding the nutritional composition of food sources is essential for healthy eating, food choices, and sustainable production and consumption (Pal et al., 2018). Fish diet contains omega-3 long-chain polyunsaturated fatty acids (n-3 LC-PUFAs) (Ajeeshkumar et al., 2021; Bienkiewicz et al., 2022; Tan et al., 2021a; Tan et al., 2021b; Tan & Zheng, 2022), bioactive compounds such as carotenoids (Tan et al., 2022) and polysaccharides (Tan et al., 2023), with beneficial effects for human health. Smaller fish are mainly consumed whole, so they have higher micronutrient concentrations than larger fish (Thilsted et al., 2016). Among these nutrients, n-3 LC-PUFAs, especially eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3), play important roles at various stages of development, including eye and brain development in newborns and infants, cardiovascular protection, and neurological development. Micro- and macro-elements play many functions in the human body, including regulating hormone levels, maintaining homeostasis, supporting mental health, strengthening bones, and supporting optimal immune function. Minerals are abundant in fish, leading major health organizations to recommend frequent consumption (Arnett et al., 2019; Connor, 1997; Innis, 2008; Li et al., 2021; Mohan et al., 2021).

National and international health guidelines recommend consuming oily fish regularly — typically 1–2 servings of ~100–200 g per week — equivalent to about 10–20 kg per person per year (Sprague et al., 2016). However, some recommend a varied intake of fish (Kris-Etherton et al., 2002) and a daily intake of 500 mg of n-3 LC-PUFA (Israel Heart Society, 2011; Vannice & Rasmussen, 2014). More than 80 % of the world's population consumes less than half of the recommended daily intake of n-3 LC-PUFA (Stark et al., 2016). Willett et al. (2019) argue for the "planet-friendly diet," replacing terrestrial meat with fish in order to achieve a balance of chicken:fish (1:1) or red meat:fish (0.5:1). This ratio is particularly abnormal in Central Europe (Roy et al., 2023), where the average blood concentration of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) is the lowest, mainly in continental areas (Stark et al., 2016). In the EU, mortality rates associated with omega-3 fatty acid deficiencies are high, especially in Central Europe, where people may consume excessive amounts of saturated fatty acids. The amount of n-3 LC-PUFA in fish can be reduced by thermal treatment (e.g., cooking) (Biandolino et al., 2023; Sardenne et al., 2021; Tenyang et al., 2022) and cold storage (chilling and freezing) (Bienkiewicz et al., 2022; Lian et al., 2022; Sardenne et al., 2021). Moreover, long-term heat treatment and cold storage alter the overall lipid profile and may further compromise the nutritional value of seafood lipids (Biandolino et al., 2023; Lian et al., 2022; Tenyang et al., 2022).

Fish are among the most important foods, providing vitamins and minerals (Onyia et al., 2013) that support children's mental and immune development (NAFDAC, 2003). All organisms require minerals, and fish are a valuable source of those and other micronutrients (Haruna, 2003).

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However, while essential in trace amounts, certain minerals can become toxic at high concentrations (Tyrrell, 2005). Anthropogenic chemicals entering the environment—primarily via water and soil—accumulate in aquatic systems and can severely harm living organisms (Conti & Cecchetti, 2001). These contaminants may enter the human food chain through fish (Duran et al., 2014), causing serious health issues whose severity depends on the type and chemical form of the heavy metals involved (Barrento et al., 2008; Tchounwou et al., 2012).

For this reason, understanding both the beneficial nutrient content and the potential contaminant levels in fish is essential for safe consumption. In the European Union, Commission Regulation 1881/2006 sets strict maximum limits for mercury, cadmium, lead, and arsenic in fisheries and seafood products. Exposure to mercury and cadmium can cause kidney damage and hypertension (Yabanli & Alparslan, 2015), whereas lead may lead to kidney failure and liver damage (Luckey & Venugopal, 1977).

Despite these nutritional and safety considerations, most consumers remain unaware of the true composition of the fish they eat. The present study therefore determined the chemical composition of five commercially available frozen freshwater fish species (carp, African catfish, trout, grass carp, and silver carp), including dry matter, ash, protein, fat, fatty acid profile, and micro- and macroelement content (Mn, Fe, Zn, Cu, S; Ca, P, Mg, Na, K).

2. LITERATURE REVIEW

2.1 Development of Hungary's live fish exports and imports

Asian countries account for more than three-quarters of total aquaculture production, with China, Japan, and Hong Kong being the most important exporters. Foreign trade activity also supports this, as the three countries' total exports account for a substantial share of global exports. Fish production in Hungary has declined. In 1990, domestic production reached 100,000 tonnes per year, but by 2010 it had fallen to 18,600 tonnes. By 2020, this value had recovered somewhat, resulting in an additional 11,000 tons of fish production. In the absence of marine access, Hungary's domestic aquaculture sector consists solely of freshwater fish and shellfish farming (Szigethy-Ambrus, 2022). Hungarian exports are relatively low and stagnant (6,760.1 billion HUF in 2021), while imports are constantly rising (41,295.5 billion HUF in 2021) (KSH, 2020). This imbalance is due to low demand for freshwater fish in the country, with consumers more interested in marine fish products.

2.2 Trends in fish consumption worldwide, in the EU, and in Hungary

In 2019, global fish consumption was 23.7 % in North America, 10.7 % in South America, 21.6 % in Europe, 9.8 % in Africa, 25.1 % in Asia, and 27.5 % in Oceania (Ashraf et al., 2020). In 2020, Europe's most significant seafood consumption was in the Mediterranean countries: Spain (645,631 tonnes), Italy (308,035 tonnes), and France (209,085 tonnes). In Hungary, the average amount of fish consumed per person is about 6 kilograms per year. The majority of fish consumed in our country is imported (marine fish), and a small portion is domestic freshwater fish. The production of freshwater fish and intensive fish farming have gained ground in our country. Fish and fish products have increased dramatically in price, further hindering their consumption (Szigethy-Ambrus, 2022).

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2.3 Brief description of freshwater fish species

- Carp (*Cyprinus carpio*): Native to Asia and Eastern Europe, including the Danube basin, carp holds major economic and recreational importance in the Carpathian basin (Edwards & Twomey, 1982; Jester, 1974; Swee & McCrimmon, 1966). This bony, ray-finned fish is a prominent member of the order Cypriniformes and family Cyprinidae. Wild carp occur in two primary forms—common and domesticated—while domesticated stock includes four varieties: scaly, mirror, side-line, and leather carp (Pintér, 2002). Its meat is generally pleasant and tasty, though it can be slightly stringy (Horváth, 2000).
- Silver carp (*Hypophthalmichthys molitrix*): Native to China and now widespread in Hungarian rivers and lakes, this species belongs to the class Actinopterygii, order Cypriniformes, and family Cyprinidae. Its fibrous, loose meat is regarded as medium-quality and low in fat. A key commercial asset is its ability to convert planktonic algae – untouched by most native fish – directly into high-value fillets. However, it is also highly invasive and can displace indigenous species in affected waters (Pintér & Pócsi, 2002).
- Trout (*Oncorhynchus mykiss*): With a native range stretching from East Asia to the Pacific coast of North America (Pintér & Pócsi, 2002), trout is distinguished by the adipose tissue behind its dorsal fin. The species is economically important because its skeleton yields clean, high-quality fillets. In Hungary, however, suitable cold, clear mountain streams and lakes are scarce, limiting large-scale production (Lajkó, 1999).
- African catfish (*Clarias gariepinus*): Originating on the African continent, this omnivorous freshwater catfish is renowned for its remarkable adaptability to extreme conditions, thriving in lakes, rivers, seasonal waters, and wetlands (Pintér & Pócsi, 2002). Its only notable weakness is a sudden immune collapse below 15 °C, necessitating warm-water farming. The meat is excellent – firm, boneless, and highly transportable – making it a prized species for aquaculture.
- Grass carp (*Ctenopharyngodon idella*): Native to China's major rivers, grass carp produces high-quality fillets – snow-white, dry, medium-firm, and tasty – yet its primary value lies in controlling harmful aquatic vegetation (Ferenczy et al., 2003).

3. MATERIALS AND METHODS

3.1 Fish sample collection and processing

Commercially available freshwater fish fillets were purchased frozen from a supermarket (*Table 1*) and thawed in a refrigerator (+ 4 °C). The skin and bones were removed from the fish. In this study, fish powder was prepared from the fillet by oven drying (UNB 400, 53 L; Memmert, Büchenbach, Germany). Then, 50 g of fish skin and 100 g of fish fillet were weighed into Petri dishes and pre-dried at 50 °C for 24 h (M1 – air-dry weight). After drying, the fish fillets and skins were ground separately to a fine powder in a grinder.

$$M1\ (g) = \frac{m1}{m0} \qquad (1)$$

m0 (g) = mass of original sample
m1 (g) = weight of dried sample after drying at 50 °C.

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Table 1: Common names, families, and species of the five fish species examined in this study

Common name	Fish Family	Species
Carp	*Cyprinidae*	*Cyprinus carpio*
African catfish	*Clariidae*	*Clarias gariepinus*
Trout	*Salmonidae*	*Oncorhynchus mykiss*
Grass carp	*Cyprinidae*	*Ctenopharyngodon idella*
Silver carp	*Cyprinidae*	*Hypophthalmichthys molitrix*

3.2 Investigations

3.2.1 Dry matter content determination

To determine true dry matter, the pre-dried and homogenized samples (5 ± 0.001 g) were further dried in an oven at 105 °C for 3 hours to constant weight (M2 – dry weight). After cooling in a desiccator, the samples were reweighed.

$$M2\ (g) = \frac{m4}{m3} \quad (2)$$

m3 (g) = air-dry sample weight before drying
m4 (g) = sample weight after drying at 105 °C.

The original dry matter content was determined using the following formula:

$$Original\ dry\ matter\ (\%) = (M1 * M2) * 100 \quad (3)$$

3.2.2 Determination of crude ash content

Previously weighed ashing crucibles were loaded with 2 ± 0.001 g of homogenized sample. The samples were incinerated in a muffle furnace at 500 °C until a constant white ash was obtained. The samples were allowed to cool in a desiccator, and their mass was then reweighed. The crude ash content of the samples can be determined using the following equation:

$$Crude\ ash\ (\%) = \frac{(m1-m2)}{m0} * 100 \quad (4)$$

m0 = mass of the homogenized sample (g)
m1 = combined mass of ash and crucible (g)
m2 = mass of the crucible (g).

3.2.3 Determination of crude fat content

The crude fat content was determined using a Foss Soxtec™ 2055 instrument. Then, 1 ± 0.001 g of the dried, homogenized sample was weighed into fat-free extraction sleeves and sealed with cotton wool. Three boiling stones were placed in the extraction jars, which were then filled with 60 mL of petroleum ether (boiling range: 40-65 °C). The extraction time was 1.5 hours (two 30-minute cycles, followed by 20 minutes and 10 minutes). After extraction, the jars were placed in a drying oven at 105 °C for 1 hour, then cooled to room temperature in a desiccator, and the crude fat percentage was calculated by reweighing.

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$$Crude\ fat\ (\%) = \frac{(m1-m2)}{m0} * 100 \quad (5)$$

m0 = mass of the homogenized sample (g)
m1 = combined mass of the jar and the fat (g)
m2 = mass of a jar containing boiling stones (g).

3.2.4 Determination of crude protein content

The crude protein content was determined using the Elementar rapidN Cube nitrogen analyzer based on the Dumas combustion method. From the dried samples, 125 ± 0.001 mg was weighed into a tin foil capsule; the samples were then compacted into pellets and placed in the device. Combustion was carried out in a stream of oxygen and carrier gas (CO_2). The device reports the protein and nitrogen content of the samples in %, using a nitrogen conversion factor of 6.25.

3.2.5 Determination of fatty acid content

Fatty acid analysis was performed following the Eder (1995) method. Total lipids were extracted from the samples as described, and fatty acid methyl esters were prepared by transesterification with boron trifluoride (BF_3) in methanol (Hewavitharana et al., 2020).
Gas chromatography was carried out on an Agilent Technologies 6890N GC System with the following settings: 10 µL injection volume, 55-minute run time, oven temperature program (170 °C for 2 min, then 200 °C for 33 min, and finally 215 °C for 20 min), carrier gases helium, nitrogen, and hydrogen, column pressure 176.7 kPa, and flow rate 20.1 mL/min. Fatty acids were identified and quantified by comparing retention times and peak areas with authentic internal standards.

3.2.6 ICP-OES

The samples were digested using a microwave digestion system (MLS 1200 MEGA; Milestone, Sorisole, BG, Italy) (*Table 2*). Digestion was carried out at 210 °C for 15 minutes, with a 15-minute temperature ramp.

Table 2: Microwave destroyer program

Program points	Time (min)	Power (W)
1.	1	250
2.	1	0
3.	8	250
4.	5	400
5.	5	650
6.	5	ventilation

For digestion, approximately 0.4 ± 0.001 g of each sample was weighed into 90 mL tetrafluoromethoxyl (TFM) digestion vessels using an analytical balance (Sartorius, TE214S). A blank was prepared by weighing 0.5 mL of high-purity water. Then, 5 mL of 65 % (m/m) nitric acid and 1 mL of 30 % (m/m) analytical-reagent-grade hydrogen peroxide were added to both the samples and the blank. The digestion vessels were sealed with a torque wrench and placed in the microwave apparatus. Digestion was performed in three replicates per sample. After the program ended, the vessels were removed, cooled to near room temperature using a water block, and opened under a fume hood. Following the destruction of the organic material, only the inorganic components

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remained for analysis. These were rinsed with 0.1 mol/dm³ nitric acid, transferred to 25 mL volumetric flasks, and made up to the mark.

After sample preparation, inductively coupled plasma optical emission spectrometry (ICP-OES) was used to determine the concentrations of micro- and macroelements in the samples (*Table 3* and *Table 4*). The analyses were performed using an Agilent 5110 Vertical Dual View instrument (Agilent, Santa Clara, CA, USA). For quantitative determination of the macroelements (Ca, K, Mg, and P), standard solutions were prepared at concentrations of 1-200 mg/L; for Na, the range was 0.1-20 mg/L. For microelements, the working range was 2.5-1000 µg/L.

Table 3: ICP-OES program test parameters

Parameters	Microelements	Macroelements
Number of items tested	5	5
Thawing time (s)	20	20
Stabilization time (s)	15	15
Observation mode	axial	radial
Observation height	-	8
Radiofrequency energy (kW)	1.4	1.4
Sample gas/nebulizer gas	0.75	0.75
Plasma gas (L/min)	12	12
Auxiliary gas (L/min)	1	1

Table 4: Wavelengths used for the determination of micro and macroelements

Microelements	λ (nm)	Macroelements	λ (nm)
S	181.972	Ca	315.880
Cu	324.754	K	766.491
Fe	234.350	Mg	279.078
Mn	293.305	Na	589.592
Zn	206.200	P	213.618

3.2.7 Statistical analysis

Statistical evaluation of the results was performed using one-way analysis of variance (ANOVA) followed by Duncan's test in SPSS 13.0 for Windows. The significance level was set at $p \leq 0.05$.

4. RESULTS

4.1 Nutrient values of fish fillet and skin

Shirmohammadli et al. (2022) analyzed the nutritional properties of carp fillet from two-year-old fish of five distinct weights. The thawed fillets were placed on ice, and the dry matter, ash, fat, and protein contents were subsequently determined. The dry matter content of the unfrozen fillets was nearly identical to that of frozen carp, although the ash content was significantly lower (1.36 ± 0.1 %) than the value we measured (*Table 5*). The fat content was higher in unfrozen fillets (9.29 ± 0.1 %). Matos et al. (2019) analyzed the composition of unfrozen

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carp fillets, reporting a fat content of 4.2 ± 0.5 % and an ash content of 0.9 ± 0.2 %. In our studies, the protein and ash contents were notably higher in frozen fish.

Matos et al. (2019) also investigated the composition of unfrozen spotted busa flesh. The reported fat and ash contents were 0.4 ± 0.1 % and 1.3 ± 0.1 %, respectively ($p < 0.05$), both significantly lower than the values we obtained from frozen fish fillets.

Shehata et al. (2018) investigated the nutritional values of hot-smoked grass carp, reporting protein (16.55 ± 0.8 %), fat (2.31 ± 0.0 %), and ash (1.87 ± 0.0 %) contents that were notably lower – likely due to smoking – than our values for frozen samples (69.71 ± 1.8 %, 20.28 ± 0.1 %, 5.37 ± 0.0 %).

Okanović et al. (2017) analyzed unfrozen grass carp fillet; the fat content was nearly equivalent (17.47 ± 2.35 %) to that of the frozen sample (20.28 ± 0.1 %), whereas the protein and ash contents were substantially lower (1.00 ± 0.2 % fat reported in error for protein/ash context).

Table 5: Nutrient content of fish fillets (%)

Fish species	Dry matter	Protein	Fat	Ash
Carp	20.45 ± 0.0^{d}	83.01 ± 0.5^{a}	5.44 ± 0.2^{e}	4.90 ± 0.1^{a}
African catfish	26.02 ± 0.0^{a}	63.23 ± 0.8^{e}	22.75 ± 0.1^{a}	4.00 ± 0.0^{c}
Trout	25.75 ± 0.0^{a}	70.05 ± 0.2^{c}	14.38 ± 0.6^{c}	4.29 ± 0.0^{b}
Grass carp	23.37 ± 0.1^{b}	69.71 ± 1.8^{b}	20.28 ± 0.1^{b}	5.37 ± 0.0^{a}
Silver carp	22.02 ± 0.1^{c}	71.97 ± 1.6^{b}	12.50 ± 0.5^{d}	5.85 ± 0.2^{a}

Data are expressed as % content ± standard deviation (n = 3). Values in the same column with different superscript letters are significantly different ($p < 0.05$) for protein content on a dry-matter basis across fish species.

In assessing the nutritional characteristics of fresh, unfrozen rainbow and brook trout, Zhelyazkov and Stratev (2019) reported protein (18.24 ± 0.1 %), fat (6.56 ± 0.1%), dry matter (26.20 ± 0.1 %), and ash (1.40 ± 0.0 %) contents. The values we recorded for frozen trout were higher, except for dry matter, which was nearly identical (25.75 ± 0.0 %). Sirakov et al. (2015) reported the nutritional composition of unfrozen rainbow and brook trout as protein (17.92 ± 2.8 %), fat (1.2 ± 0.2 %), and ash (1.16 ± 0.0 %), all of which were markedly lower than our values for frozen samples.

The composition of unfrozen African catfish fillet showed protein (78.31 %), ash (4.72 ± 0.1 %), and dry matter (26.25 ± 0.3 %) contents nearly identical to those of the frozen sample (Edea et al., 2018). Deng et al. (2016) analyzed chilled African catfish from markets and farms, reporting dry matter (26.67 ± 6.08 % and 24.98 ± 2.09 %), protein (30.86 ± 0.68 % and 30.98 ± 0.55 %), and ash (1.67 ± 0.51 % and 1.32 ± 0.26 %) – nearly identical between sources. Our frozen African catfish had comparable dry matter (27.29 ± 0.0 %) but significantly higher protein (70.74 ± 1.1 %) and ash (11.24 ± 0.6 %) contents.

For frozen carp skin, Jalili et al. (2021) reported protein (19.36 ± 0.5 %), fat (2.47 ± 0.2 %), and ash (1.69 ± 0.2 %) contents – values notably lower than ours (*Table 6*). Huang et al. (2023) analyzed frozen carp skin and reported protein (80.04 ± 1.2 %) and ash (2.02 ± 1.4 %), which were nearly identical to our results, whereas fat (10.99 ± 1.0 %) was significantly lower than our value (19.67 ± 0.2 %).

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Table 6: Nutrient content of fish skin (%)

Fish species	Dry matter	Protein	Fat	Ash
Carp	33.96 ± 0.1^{d}	75.30 ± 0.3^{a}	19.67 ± 0.2^{d}	2.72 ± 0.0^{d}
African catfish	27.29 ± 0.0^{e}	70.74 ± 1.1^{b}	13.69 ± 0.1^{e}	11.24 ± 0.6^{a}
Trout	39.76 ± 0.1^{a}	43.95 ± 0.5^{e}	38.45 ± 0.1^{a}	5.25 ± 0.4^{c}
Grass carp	37.15 ± 0.0^{b}	49.51 ± 1.3^{d}	36.49 ± 0.5^{b}	9.27 ± 0.0^{b}
Silver carp	36.07 ± 0.2^{c}	56.70 ± 1.8^{c}	33.57 ± 0.3^{c}	5.11 ± 0.0^{c}

Data expressed as the % content ± standard deviation (n = 3). Values in the same column with different superscript letters are significantly different (P < 0.05) between the fish species.

4.2 Fatty acid composition

Kheiri et al. (2022) also examined frozen fillets of carp and silver carp from both winter and summer seasons. The SFA (34.48 ± 2.10 % and 32.64 ± 4.92 %) and MUFA (31.50 ± 3.76 % and 36.37 ± 4.91 %) values for both carp and silver carp were higher in summer, while PUFA (31.77 ± 2.23 % and 37.96 ± 4.92 %), n-3/n-6 (2.45 ± 1.03 % and 3.75 ± 0.76 %), and PUFA/SFA (1.19 ± 0.11 % and 1.39 ± 0.16 %) values were higher in winter. Our silver carp values were similar to the summer values, except for the n-3/n-6 ratio (1.66 %), which was much lower – even than carp (0.45 %) – compared to the values reported by Kheiri et al. for fish caught in summer and winter (silver carp: 3.04 ± 0.93 % and 3.75 ± 0.76 %; carp: 2.13 ± 2.16 % and 2.45 ± 1.03 %). For carp, PUFA and PUFA/SFA were similar to summer values (19.57 ± 1.58 % and 0.57 ± 0.07 %), while SFA matched the winter value (26.76 ± 2.48 %). The MUFA value was much higher in our carp than in either period (31.50 ± 3.76% and 30.09 ± 5.41 %) (*Table 7*). This elevated MUFA may be due to differences in feed, age, or farming practices (Mohamad et al., 2022).

Mohamad et al. (2022) examined 4–5-month-old African catfish fillets (*C. gariepinus*) from a private farm fed 50 % commercial pellets and 50 % poultry by-product meal, 9–12-month-old Asian catfish fillets (*C. macrocephalus*) from rice fields, and 5-6-month-old hybrids (CM×CG) from a freshwater breeding aquarium fed 100 % pellets containing 35 % crude protein. The highest SFA value was observed in unfrozen Asian catfish from rice fields (48.21 ± 5.11 %), possibly due to their age (9-12 months). The SFA (32.15 ± 1.23 %), MUFA (45.24 ± 3.21 %), PUFA (22.61 ± 2.11 %), n-6/n-3 (7.97 ± 2.19 %), and n-3/n-6 (0.13 ± 0.04 %) values of African catfish closely matched our results for frozen fillet (*Table 7*), suggesting similar age and rearing conditions. In the hybrid, the highest PUFA value was 31.41 ± 0.94 %, likely due to crossbreeding.

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Table 7: Average percentage of fatty acid composition (%) in freshwater fish fillet

Fish species	Carp	African catfish	Trout	Grass carp	Silver carp
SFA	25.84 ± 0.1^{d}	35.74 ± 0.0^{c}	41.22 ± 0.3^{b}	42.50 ± 0.1^{a}	36,09 ± 0.3^{c}
MUFA	58.70 ± 0.3^{a}	41.01 ± 0.3^{c}	34.49 ± 0.2^{d}	45.00 ± 0.2^{b}	35,85 ± 0.4^{d}
PUFA	11.49 ± 0.4^{d}	22.14 ± 0.2^{b}	40.75 ± 0.2^{a}	41.63 ± 0.1^{a}	18,35 ± 0.5^{c}
UFA	70.19 ± 0.2^{c}	63.15 ± 0.2^{d}	75.24 ± 0.1^{b}	86.64 ± 0.1^{a}	54,20 ± 0.2^{e}
n6	7.90 ± 0.2^{d}	18.70 ± 0.1^{b}	28.31 ± 0.0^{a}	15.03 ± 0.1^{c}	6,30 ± 0.1^{e}
n3	3.57 ± 0.2^{d}	3.44 ± 0.1^{d}	12.35 ± 0.0^{a}	5.74 ± 0.0^{c}	10,49 ± 0.2^{b}
n6/n3	2.22	5.43	2.29	2.62	0.60
n3/n6	0.45	0.18	0.44	0.38	1.66
PUFA/SFA	0.44	0.62	0.99	0.98	0.51

SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; UFA: unsaturated fatty acids; n-6: omega-6 polyunsaturated fatty acids; n-3: omega-3 polyunsaturated fatty acids. Different lowercase letters between lines indicate significant differences between species ($p < 0.05$).

The wild brown and cultured rainbow trout examined by Guler et al. (2017) were 2 years old and weighed 250-300 g. The fillets were stored frozen (−26 °C) until analysis; the study was conducted on samples at room temperature. A significant difference ($P \leq 0.05$) in SFA content between wild brown trout (28.38 ± 1.51 %) and cultured rainbow trout (25.80 ± 0.62 %) may be attributed to differences in diet and feeding systems. Cultured rainbow trout contained more MUFA (29.20 ± 1.56 %) than wild brown trout (26.84 ± 1.98 %), whereas our measured value was higher for both (34.49 ± 0.2 %). Environmental conditions and diet influence the fatty acid composition of wild and cultured fish. A significant difference ($P \leq 0.05$) in PUFA was also observed between wild brown trout (44.77 ± 0.88 %) and cultured rainbow trout (45.01 ± 1.75 %), though our values were significantly lower. The PUFA content in fish muscle depends on the diet (Sargent, 1997). Changes in feeding habits may alter fatty acid profiles (Norobin, 1990).

Several studies have shown that wild fish generally have higher ω-3 fatty acid content than farmed fish, likely due to the absence of phytoplankton-derived nutrients in commercial feeds (Ackman & Takeuchi, 1986; Ozogul et al., 2013). Guler et al. (2017) reported higher ω-3 levels in wild brown trout (35.52 ± 1.62 %) than in cultured rainbow trout (27.43 ± 1.56 %). Our measurements suggest the trout were commercially farmed. The ω-3/ω-6 ratio was higher in wild brown trout (3.84 %) than in cultured rainbow trout (1.56 %), and our values were significantly lower still. This ratio depends on feed composition (Steffens, 1997) and serves as a valuable indicator of the nutritional value of fish oils (Pigott & Tucker, 1990). Simopoulos (2004) noted that the ideal ω-6/ω-3 ratio is 1:1, whereas Western diets often exceed 16:1. Excessive ω-6/ω-3 intake is linked to cardiovascular disease, cancer, and inflammatory and autoimmune disorders. Ateş et al. (2013) reported seasonal variation in the fatty acid composition of wild brown trout, with ω-3/ω-6 ratios similar to those of Guler et al. (2017). The PUFA/SFA ratio is nutritionally significant, with a 1:1 balance considered ideal. Among PUFAs, essential omega-3 and omega-6 fatty acids must be obtained from the diet, as the body cannot synthesize them (Szakály, 2007).

The fatty acid composition of grass carp meat caught in summer and autumn was studied after frozen storage (−20 °C) by Kovacik et al. (2024), who reported values in autumn similar to ours for SFA (42.99 ± 6.40 %), n-3 (9.58 ± 3.1 %), n-6 (13.80 ± 1.8 %), and n-6/n-3 (1.53 ± 0.4 %). Their MUFA (autumn: 33.62 ± 8.77 %; summer: 35.30 ± 13.90 %) and PUFA (autumn: 23.38 ± 4.48 %;

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summer: 24.21 ± 6.20 %) values were lower than ours. Guler et al. (2008) examined seasonal effects in common carp and found the highest MUFA in winter (41.1 %) and the highest PUFA in summer (42.8 %). These values were similar to our results for grass carp, a fellow member of the cyprinid family. Changes in fatty acid composition are related to the fish's diet.

4.3 Micro- and macronutrient content

The microelement content of unfrozen grass carp and carp fillets was examined by Saha et al. (2020), who reported higher Fe (33.33 and 30.00 mg/kg dry weight), Cu (21.70 and 24.67 mg/kg dry weight), and Zn (20.60 and 25.82 mg/kg dry weight) than our values (*Figure 1*). For macroelements, Saha et al. (2020) reported Na (350.76 and 500.78 mg/kg dry weight), K (498.67 and 587.32 mg/kg dry weight), and Ca (676.41 and 857.14 mg/kg dry weight) in unfrozen fish – values significantly lower than ours for frozen fish (Na: 1,708.0 and 1,009.0 mg/kg dry weight; K: 14,460.0 and 14,610.0 mg/kg dry weight; Ca: 5,352.0 and 2,257.0 mg/kg dry weight) (*Figure 2*).

Dziura et al. (2024) reported lower Fe (6.9 ± 2.3 mg/kg dry weight), Cu (1.1 ± 0.3 mg/kg dry weight), and Zn (2.8 ± 0.9 mg/kg dry weight) in unfrozen carp fillet than in our frozen samples (Fe: 21.55 ± 2.5; Cu: 2.37 ± 15.5; Zn: 23.63 ± 0.6 mg/kg dry weight). Manganese was higher in unfrozen fillet (0.9 ± 0.2 mg/kg dry weight) than in frozen fillet (0.71 ± 8.0 mg/kg dry weight). Dziura et al. (2024) also reported significantly lower macroelement concentrations – K (4,005 ± 35 mg/kg dry weight), Na (401 ± 20 mg/kg dry weight), Ca (334 ± 88 mg/kg dry weight), and Mg (301 ± 26 mg/kg dry weight) – than our values (*Figure 2*).

Gokoglu et al. (2004) measured lower Ca (468 mg/kg), Na (182 mg/kg), Mg (169 mg/kg), Zn (7 mg/kg), Cu (0.09 mg/kg dry weight), K (2,100 mg/kg), and Mn (0.56 mg/kg) in farmed trout compared to our results. Similarly, Siemianowska et al. (2016) reported lower K (4,393.4 mg/kg), Na (527.7 mg/kg), Ca (267.2 mg/kg), Mg (316.9 mg/kg), Fe (5.0 mg/kg), Zn (5.0 mg/kg), and Cu (0.46 mg/kg dry weight) in rainbow trout reared in flow-through systems than in our samples. However, trout raised in recirculation systems had higher Ca, Na, Zn, Mg, and K than those from conventional farms (Siemianowska et al., 2016).

Aleksic et al. (2025) examined the micro- and macroelement content in frozen samples of carp, silver carp, and European catfish caught from three Danube habitats. Significant differences were observed for some elements across habitats. In carp, Mn and Zn were similar across sites (0.493-0.606 and 26.90-31.00 mg/kg dry weight), whereas Fe and Cu were significantly lower (4.85-8.72 and 0.213-0.351 mg/kg dry weight) than our values (21.55, 2.37, and 9,961.0 mg/kg dry weight). For macroelements, Ca was comparable (1,162-2,707 mg/kg dry weight) to our result (2,257.0 ± 11.5 mg/kg dry weight), while Mg, Na, and K were significantly lower (215.27-266.51; 455-521; and 2,713-2,786 mg/kg dry weight) than ours (1,279.0 ± 1.6; 1,708.0 ± 1.2; and 14,460.0 ± 1.2 mg/kg dry weight). In African catfish, our Fe and Zn values were significantly higher than those in European catfish from the Danube (3.12-5.00 and 6.34-7.69 mg/kg dry weight).

Mn and Cu were similar between African and European catfish (0.340-0.355 and 0.101-0.133 mg/kg dry weight; *Figure 1*). European catfish had significantly higher Ca (1,360-1,660 mg/kg dry weight) than African catfish (291.5 mg/kg dry weight). In contrast, Mg, Na, and K were higher in African catfish (1,101.0; 1,516.0; and 14,210.0 mg/kg dry weight) than in the European species (223-254; 473-577; and 2,935-3,378 mg/kg dry weight). For silver carp, Mn and Fe were similar between studies (1.22-2.73 and 8.44-21.08 mg/kg dry weight) and our values (2.00 ± 7.4 and 12.49 ± 1.4 mg/kg dry weight). However, our Zn and Cu were significantly higher (18.18 ± 3.9 and 1.69 ± 14.6 mg/kg dry weight) than those reported by Aleksic et al. (2025) (8.54-10.59;

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0.272-0.639; and 0.1115-0.1483 mg/kg dry weight). All macroelements (Ca, Mg, Na, K) were significantly higher in our samples (*Figure 2*) than in Danube-caught silver carp (1,134-2,360; 229.0-276.1; 356.7-581.1; and 2,889-3,207 mg/kg dry weight).

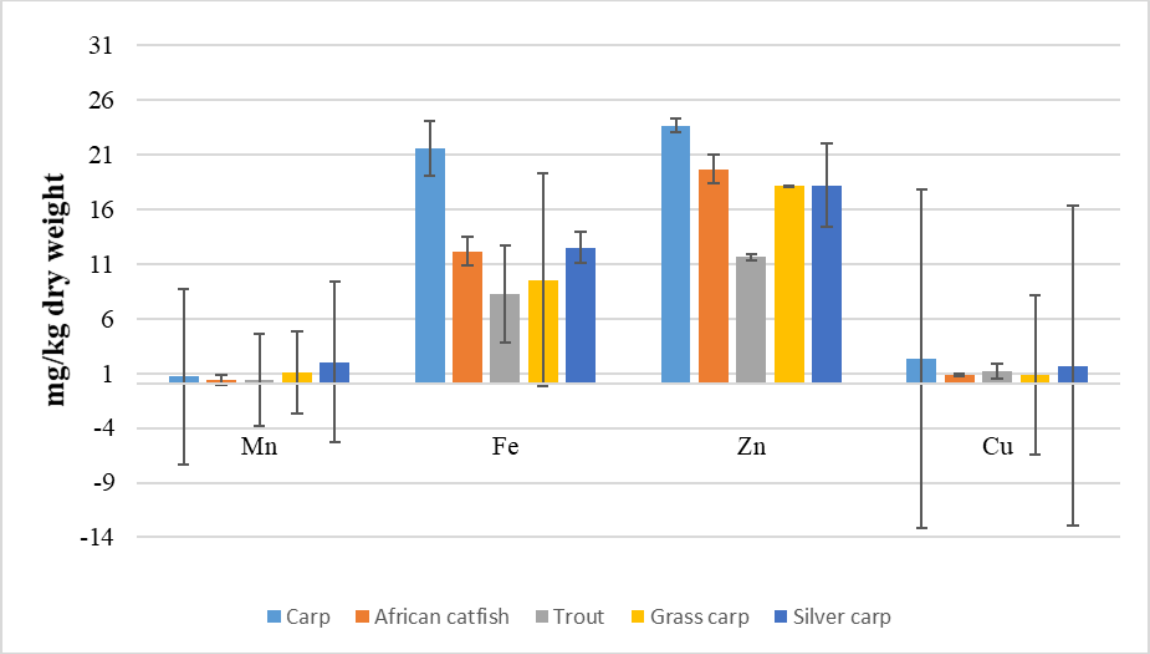

Figure 1: Microelements in freshwater fish

Mn: Manganese, Fe: Iron, Zn: Zinc, Cu: Copper.

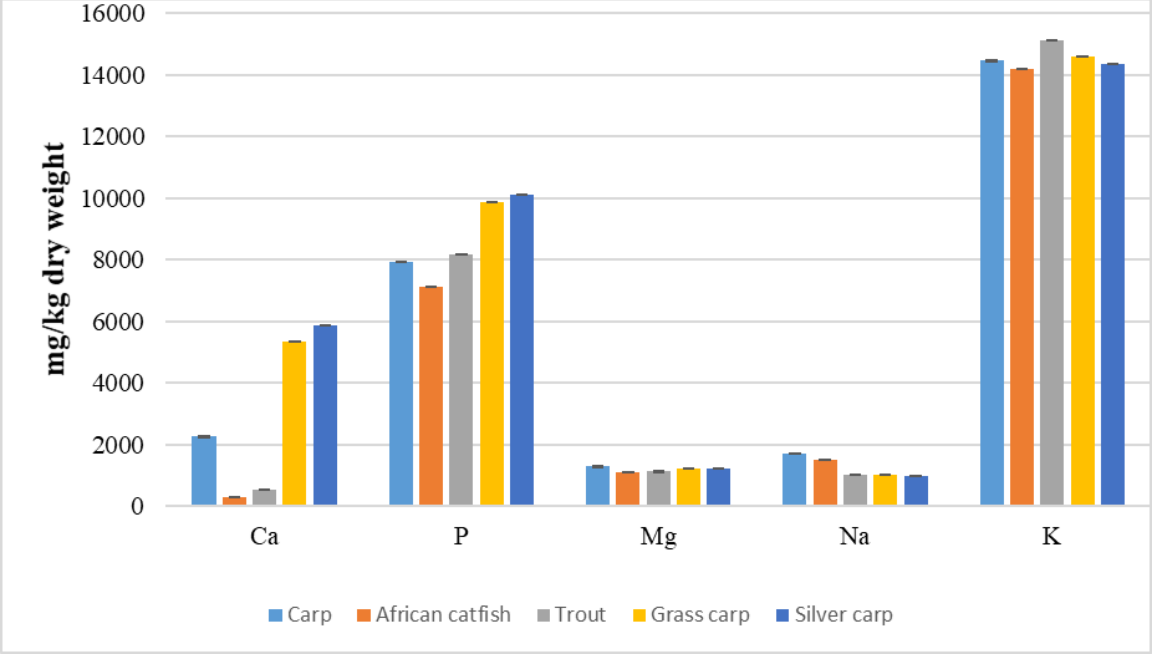

Figure 2: Macroelements in freshwater fish

Ca: Calcium, P: Phosphorus, Mg: Magnesium, Na: Sodium, K: Potassium.

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5. CONCLUSION

This study compared the nutrient profiles of commercially available frozen freshwater fish with literature values for unfrozen specimens.

Protein was highest in carp (83.01 ± 0.5 %) and silver carp (71.97 ± 1.6 %), both notably above the usual 70-78 % dry-basis range for muscle tissue; carp skin also showed high protein (75.30 ± 0.3 %). Fat content was highest in African catfish (22.75 ± 0.1 %) and grass carp (20.28 ± 0.1 %), with trout skin reaching 38.45 ± 0.1 % compared to its fillet.

Grass carp exhibited the highest SFA (42.50 ± 0.1 %), PUFA (41.63 ± 0.1 %), and total UFA (86.64 ± 0.1 %), with a PUFA/SFA ratio of 0.98. Carp fillet had the highest MUFA (58.70 ± 0.3 %), whereas trout fillet showed elevated n-6 (28.31 ± 0.0 %) and n-3 (12.35 ± 0.0 %).

Mineral profiles varied markedly: carp contained the highest Fe (21.55 ± 2.5 mg/kg), Zn (23.63 ± 0.6 mg/kg), Cu (2.37 ± 15.5 mg/kg), Mg (1,279.0 ± 1.6 mg/kg), and Na (1,708.0 ± 1.2 mg/kg dry weight); silver carp led in Mn (2.00 ± 7.4 mg/kg), Ca (5,855.0 ± 3.8 mg/kg), and P (10,100.0 ± 1.4 mg/kg dry weight); and trout in K (15,140.0 ± 0.7 mg/kg dry weight).

Because this study compared commercially available frozen samples with literature values for unfrozen the results are meaningful but not definitive and highlight the need for further research. Nonetheless, they confirm that commercially available frozen freshwater fish remain valuable sources of protein, essential polyunsaturated fatty acids, and micro- and macroelements.

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Fagyasztott édesvízi halak tápanyag-, zsírsav-, mikro- és makrotápanyag-tartalmának meghatározása

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ÖSSZEFOGLALÁS

Az egészséges táplálkozás, az élelmiszer kiválasztása és a fenntartható termelés és fogyasztás szempontjából fontos az élelmiszerforrás tápanyag-összetételének megértése, megismerése. A tanulmány célja, hogy a leggyakrabban fogyasztott fagyasztott édesvízi halfajok beltartalmi értékeit, zsírsavösszetételét és mikro-, makroelem tartalmát meghatározzuk.

Az eredmények azt mutatják, hogy a fagyasztott édesvízi halfajok beltartalmi értékei közel azonosak voltak a friss halból végzett mérésekhez viszonyítva. A legnagyobb fehérje tartalmú fagyasztott halfaj a ponty volt (83,01 ± 0,5 %), míg a zsírtartalma az afrikai harcsa (22,75 ± 0,1 %) esetében volt nagyobb. A halbőr fehérje tartalma szintén a pontynál (75,30 ± 0,3 %), a zsírtartalma a pisztrángnál volt a legnagyobb (38,45 ± 0,1 %) a halhúshoz képest. SFA, PUFA, UFA tartalom (42,50 ± 0,1; 41,63 ± 0,1; 86,64 ± 0,1 %) az amurnál volt a legnagyobb. MUFA a ponythúsnál (58,70 ± 0,3 %) volt szignifikánsan a legnagyobb. Mikro-, makroelemek esetében a fagyasztott pontyhús Fe, Zn, Cu (21,55 ± 2,5; 23,63 ± 0,6; 2,37 ± 15,5 mg/kg száraztömeg) tartalma szignifikánsan nagyobb volt a többi mintához képest, míg a Mn a fehér busában volt nagyobb (2,00 ± 7,4 mg/kg száraztömeg). A Ca, P tartalom a fehér busánál (5855,0 ± 3,8; 10100,0 ± 1,4 mg/kg száraztömeg), Mg, Na a pontynál (1279,0 ± 1,6; 1708,0 ± 1,2 mg/kg száraztömeg), K a pisztrángnál (15140,0 ± 0,7 mg/kg száraztömeg) volt szignifikánsan nagyobb a többi halfajhoz képest.

Az eredmények azt mutatták, hogy a fagyasztott édesvízi halfajok is megfelelő forrásai a szükséges többszörösen telítetlen zsírsavaknak és mikro, makroelemeknek.

Kulcsszavak: édesvízi halak, tápanyagösszetétel, zsírsavösszetétel, mikroelemek, makroelemek

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