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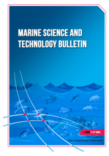

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RESEARCH ARTICLE

Nutrient quality of cultured fish species in the Black Sea: Evaluation of fatty acids, amino acids and fillet colors

Dilara Kaya Öztürk[1*]

[1] *Sinop University, Faculty of Fisheries and Aquatic Science, Department of Aquaculture, Sinop, Türkiye*

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ABSTRACT

This study aims to examine the nutritional composition (amino acid and fatty acid) and fillet color of commercially produced cultured fish of the Black Sea. All fish species [(sea bass (*Dicentrarchus labrax*), sea bream (*Sparus aurata*), turbot (*Scophthalmus maximus*), and large rainbow trout (*Oncorhynchus mykiss*)] were collected from the Black Sea's aquaculture sites in 2020. Total amino acid values of fillets were listed as sea bream>turbot>large rainbow trout>sea bass fillet. The highest omega-3/omega-6 ratio was in turbot fillets, and the highest omega-6/omega-3 ratio was in sea bass and sea bream fillets ($p<0.05$). Consequently, it was concluded that the fish cultured from the Black Sea have excellent nutritional values, including high amounts of unsaturated fatty acids and appropriate amounts of essential amino acids and the cultured fish in the Black Sea are of good quality, nutritious and beneficial for human consumption.

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Introduction

Aquaculture has developed into a major global industry since the introduction of intensive aquaculture in the 90s. With this development, worldwide aquaculture production reached 75.4 million tons in 2019 (FAO, 2021). This development in aquaculture has affected the Black Sea economically, socially and culturally for generations as well as the world. Today, the aquaculture sector is expanding and becoming an increasingly significant aspect of the Black Sea economy, with output quantities exceeding 700,000 tons in 2019 (FAO, 2022). The modern aquaculture sector in Türkiye emerged in the mid-1970s, with the beginning of commercial freshwater farming of rainbow trout (*Oncorhynchus mykiss*). A decade later, in the mid-1980s, Türkiye's first commercial sea bass (*Dicentrarchus labrax*), and sea bream (*Sparus aurata*), hatchery introduced the country to marine aquaculture (FAO, 2022). Türkiye's aquaculture industry is now a vibrant and competitive seafood production sector that is well integrated into international

* Corresponding author
E-mail address: dilara.kaya55@gmail.com (D. Kaya Öztürk)

seafood markets. The sector also contributes significantly to national and international food security, as well as revenue, employment, and economic growth. Turkish aquaculture production is dominated by three species: rainbow trout, seabass and sea bream. For many years freshwater aquaculture (i.e., farming of rainbow trout) was the backbone of the sector; however, more recently, marine aquaculture (mainly seabass and seabream) has begun to take the lead in farmed fish output. Along with the growth of marine aquaculture along Türkiye's Black Sea coast, cage farming of large rainbow trout, branded as Turkish salmon, is becoming a major component of the economy (FAO, 2022). Aquaculture practices of turbot (*Scophthalmus maximus*), are vital to meet the high market demand. In addition to commercial turbot production in recent years, juvenile turbots were released into nature in order to increase the stock biomass (Maslova, 2002; Aydın, 2021).

The world's leading health authorities widely recommend consuming fish on a regular basis as part of a healthy diet due to their high nutrient content including protein, fat, vitamin, and minerals (WHO, 2003; EFSA, 2009). In the global fight against malnutrition, fish products are a much healthier food source than terrestrial meat products. On a global scale, fish products are the third most important source of dietary protein consumed by humans after cereals and milk, accounting for 17.1% of the total animal protein supply (VKM, 2014; Bogard et al., 2015; FAO, 2018). Fish has a higher protein content on an edible weight basis than most terrestrial meats, a lower caloric density, and is generally much leaner than red and processed meats, has the highest content of omega-3 polyunsaturated fatty acids of any animal food, and has a higher mineral and vitamin content than most terrestrial meats and processed meat products (Tacon & Metian, 2013; USDA, 2018). Furthermore, considerable scientific evidence exists regarding the direct health benefits of consuming fish, such as a lower risk of death from coronary heart disease and stroke, a long er gestation period and improved visual and cognitive development, improved neurodevelopment in infants and children when fish is consumed before and during pregnancy (Forouhi et al., 2018). Although it has been proven that consuming fish is so healthy, it is a known fact that the consumption of aquatic products is very low in developing countries. For example, the average per capita consumption of fish in Türkiye is very low compared with other European countries and in 2019 amounted to 6.3 kg/year. (Anonymous, 2021). This consumption amount is affected by factors such as socioeconomic status, lack of education, product availability, food safety, and especially the prejudice towards cultured fish. Many studies were carried out in which wild and cultured fish are compared and fillet quality values of cultured fish are determined in order to break down such prejudices (Fuentes et al., 2010; Baki et al., 2015; Colombo & Mazal, 2020; Tarricone et al., 2022). The current study aimed to analyze and compare the biochemical composition, in terms of amino acid, fatty acid, and fillet color, of available cultured fish fillets produced in the Black Sea (large rainbow trout, turbot, sea bass, and sea bream).

Materials and Method

Fish, Diets and Sampling Areas

In the study, sea bass (*Dicentrarchus labrax*), sea bream (*Sparus aurata*), turbot (*Scophthalmus maximus)*, and large rainbow trout, (*Oncorhynchus mykiss)* were used cultured. All fish species were collected from aquaculture sites in the Black Sea (Sinop, Samsun, and Trabzon), in 2020. All collection sites are located in the Black Sea and species information, fish number, and site location are shown in Supplementary file Table S1. It was preferred that the cultured fish used in the study should be at least in portion weight in order to give clear results to the consumers. Large rainbow trout, sea bream and sea bass were produced in cage systems, while the turbot was produced in a recirculating aquaculture system. The fish were sampled by the operating personnel while they were harvested, therefore this manuscript does not need an ethical approval. Fish and diet samples were transported to Sinop University, laboratory of the Aquaculture and Sinop University Scientific and Technological Research Center (SUBITAM) by providing cold chain conditions with Igloo Island Breeze brand wheeled ice cooler with in-house ice accumulator. After biometric measurements were made in the laboratory, skinless and boneless fillets of fish were removed and stored in a deep freezer (WiseCryo/WUF-D500-80°C) until analysis. Biometric data (viscerosomatic, hepatosomatic and gonadosomatic index, carcass yield, and condition factor) used in the study were obtained from Owatari et al. (2022).

The diets were made by BioMar SAGUN (D1) (Aydın-Türkiye), Sürsan Inc. (D2) (Samsun- Türkiye) and Noordzee Inc. (D3) (Muğla- Türkiye) the commercial diet manufacturer, using a closed formula for large rainbow trout, turbot, sea bass and bream, respectively. (The biochemical, amino and fatty acid compositions of the diets are given Supplementary file Table S2).

Biochemical Analyses

The biochemical content (crude protein, crude fat, crude ash and dry matter) of the diet and fillet samples was evaluated using AOAC (1995) approved procedures. All biochemical analysis in fish fillets were made from the wet basis and three repetitions.

Amino Acid Analyses

Amino acid analyzes of diets and fillets were made by Sinop University Scientific Research and Application Center (SUBITAM). Amino acid analyses of diet and fish fillets were performed using the Jasem LC-MS/MS amino acid assay kit. The total amino acids and quality of amino acids were calculated from the following formulas given below (Li et al., 2009):

Fatty Acid Analyses

Fatty acid analyzes of diets and fillets were made by Sinop University Scientific Research and Application Center (SUBITAM). The fillet and diet samples were converted to methyl esters by derivatization of fat samples in a gas chromatography device (Thermo Scientific Trace 1310) for fatty acid analyses. Moreover, the quality of acquired fatty acids was established using peroxidisability index (PI) (Arakawa & Sagai, 1986), atherogenicity index (AI), thrombogenicity index (TI) (Ulbricht & Southgate, 1991) and hypo-cholesterolaemic/hypercholesterolaemic ratio (HH) (Santos-Silva et al., 2002).

Fillet Color

The color values of fillets of cultured fish of the Black Sea were assessed using Minolta Chroma Meter, standardized to a white plate as a reference before each measurement (standard values for white plate L*=91.97; a*=−1.4; b*=2.0, Standard C2-22326). L*, a* and b* values represent lightness, redness and yellowness, respectively. The Hue is a descriptor of what is generally understood to be the true color, and the chroma (C*) is the intensity or degree of saturation of the color. The angle of Hue and C* was calculated using a* and b* values (Hernández et al., 2009): C*=$\sqrt{a^{*2}+b^{*2}}$ c and $Hue = \arctan(b^{*}/a^{*})$.

Color measurement of fillet and skin of cultured fish of the Black Sea was done from three locations: 1st location: between behind of the operculum; 2nd location: under the dorsal fin; and 3rd location: front of the caudal fin.

Essential Amino Acids (EAA)= Histidine + Lysine+ Phenylalanine+ Methitonine+ Threonine+ Leucine+ Isoleucine+Valine+ Arginine

Semi-Essential Amino Acids (SEAA)= Histidine + Arginine

Non-Essential Amino Acids (NEAA)= Alanine+ Aspartic acit+ Glutamic acit+ Tyrosine+ Glicine+ Serine+ Proline

Branched-chain amino acid (BcAA)= Leucine+ Isoleucine+ Valine

Sulfur-containing amino acids (SAA)= Cystine+ Methinonine

Aromatic amino acids (ArAA)= Phenylalanine+ Tyrosine

Basic (alcaline) amino acids (BAA)= Lysine+ Arginine+ Histidine

Acidic amino acids (AAA)= Aspartikc acid+ Glutamic acid

Total saturated fatty acids (ΣSFA) = C12:0 + C13:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C21:0 + C22:0 + C23:0 + C24:0

Total mono unsaturated fatty acids (ΣMUFA) = C14:1 + C15:1 + C16:1 + C17:1 + C18:1n-9c + C18:1n-9t + C20:1n-9c + C22:1n-9 + C24:1

Total poly unsaturated fatty acids (ΣPUFA) = C18:2n-6t + C18:2n-6c + C18:3n-3 + C18:3n-6 + C20:2 + C22:2 + C20:3n-6 + C20:5n-3 + C20:4n-6 + C22:6n-3

ΣOmega-3 = C18:3n-3+C20:3n-3+C20:5n-3+C22:5n-3+C22:6n-3;

ΣOmega-6 = C18:2n-6t + C18:2n-6c+ C18:3n-6+ C20:4n-6+ C20:3n-6

ΣOmega-9 = C18:1n-9c+ C18:1n-9t+ C20:1n-9c+ C22:1n-9

Atherogenicity Index (AI)= [(C12:0+(4 x C14:0)+C16:0)] / (MUFA+Omega-3+Omega-6)

Thrombogenicity Index (TI)= (C14:0+C16:0+C18:0) / [(0.5 x MUFA) + (0.5xOmega-6) + (3xOmega-3) + (Omega-3/Omega-6)]

Hypocholesterolemic/Hypercholesterolemic ratio (HH)= (C18:1n-9+C18:2n-6+C18:3n-3+C20:4n-6+C20:5n-3+C22:6n-3) / (C14:0+C16:0)

Peroxidisability index (PI)= (MUFAx0.025) + (C18:2n-6+C20:2) x 1 + [(C18:3n-6+C18:3n-3)x2] + [(C18:4n-3+C20:4n-6+C22:4n-6) x 4] + [(C20:5n-3+C22:5n-3) x 6] + [(C22:6n-3) x 8]

Statistical Analysis

The data were reported as average values with standard error (SE). The IBM SPSS 21 statistics package application was used for statistical analysis. Shapiro–Wilk normality and Levene's tests were used to determining the data's normality and equality of variance. The significance of the differences in the data was determined using one-way ANOVA, followed by Tukey's procedure for multiple comparisons. Regression analyses were used to examine the relationships between the values.

Results

Biometric Data

The study aimed to determine the meat quality values of the sea fish cultured in the Black Sea, at the weight reached by the consumer. The weights (g) and biometric data [(hepatosomatic (HSI), viscerosomatic (VSI) and gonadosomatic (GSI) index and carcass yield (CY), %)] of cultured fish in the Black Sea are given Table 1. In this study, average harvest weights of large rainbow trout, turbot, sea bass, and sea bream sampled at the same time were determined as 1556.36±140.81, 761.30±42.56, 533.18±56.76, and 759.36±32.40 g, respectively Gonad formation was observed only in turbot and large rainbow trout, and gonadosomatic index (GSI) values were calculated only for these fish. While the highest hepatosomatic index (HSI) values of cultured fish in the Black Sea were determined in sea bass and the lowest in large rainbow trout ($p<0.05$), Viscerosomatic index (VSI) values were determined to be the highest in large rainbow trout and the lowest in sea bream ($p<0.05$). The carcass yield (CY) values of four different cultured fish with high economic value was large rainbow trout>sea bass>sea bream>turbot.

Biochemical Composition

The biochemical composition of cultured fish fillet of the Black Sea is given in Table 2. The dry matter values (DM) of the cultured fish fillet of the Black Sea were as sea bream>large rainbow trout>sea bass>turbot, and the statistical difference was significant ($p<0.05$).

The crude protein (CP) ratio of fish fillets was highest in sea bream and lowest in turbot, and the CP ratios of turbot fillets were statistically different from the CP ratios of other cultured fish fillets in the Black Sea ($p<0.05$). The crude fat ratio (CF) was determined as highest in large rainbow trout fillets and lowest in turbot fillets ($p<0.05$).

Amino Acid Composition

The amino acid composition of cultured fish fillets of the Black Sea is shown in Table 3. The highest essential amino acid in cultured fish fillets was determined lysine, and the non-essential amino acid was glutamic acid. Except for ornithine (highest in large rainbow trout fillets) and cystine (highest in turbot fillets) in fish fillets, all amino acid values were highest in sea bream fillets. The proline value was determined to be similar in sea bream and turbot fillets.

Table 1. The weights (g) and biometric data [(hepatosomatic (HSI), viscerosomatic (VSI) and gonadosomatic (GSI) index and carcass yield (CY), %)] of cultured fish in the Black Sea

Fish Species	Weight (g)	HSI (%)	VSI (%)	GSI (%)	CY (%)
Large rainbow trout	1556.36±140.81	$1.68±0.16^{a}$	$16.48±1.33^{c}$	$7.16±3.29^{b}$	$44.23±1.66^{c}$
Turbot	761.30±42.56	$2.46±0.22^{b}$	$8.41±0.69^{a}$	$0.77±0.16^{a}$	$27.37±1.43^{a}$
Sea bass	533.18±56.76	$3.27±0.74^{c}$	$12.95±0.95^{b}$	-	$44.08±0.22^{c}$
Sea bream	759.36±32.40	$1.74±0.17^{a}$	$8.07±0.87^{a}$	-	$38.87±2.00^{b}$

Note: Each value means mean±standard error. Values expressed with different exponential letters on the same column are statistically different from each other ($p<0.05$).

VSI (%) = (Viscera weight, g/Total body weight, g) × 100

HSI (%) = (Liver weight, g/Total body weight, g) × 100

GSI (%) = (Gonad weight, g/Total body weight, g) × 100

CY (%) = (Edible fillet weight, g/Total body weight, g) × 100

Table 2. Biochemical composition of cultured fish fillets in the Black Sea

Biochemical Composition (%)	*Large Rainbow Trout*	*Turbot*	*Sea Bass*	*Sea Bream*
Crude protein	20.54±0.50^{b}	16.60±0.95^{a}	21.96±0.35^{b}	22.00±0.35^{b}
Crude fat	11.21±0.12^{c}	2.49±0.16^{a}	8.20±0.06^{b}	10.12±0.69^{bc}
Crude ash	4.15±0.02^{b}	3.82±0.11^{a}	3.85±0.13^{a}	4.26±0.10^{b}
Dry matter	35.94±0.42^{b}	22.98±0.35^{a}	35.08±0.49^{b}	36.41±0.35^{bc}

Note: Each value means mean±standard error. Values expressed with different exponential letters on the same line are statistically different from each other ($p<0.05$).

Table 3. Amino acid composition of cultured fish fillets in the Black Sea (g/100g)

Amino Acids (g/100g)	**Large Rainbow Trout**	**Turbot**	**Sea Bass**	**Sea Bream**
Alanine	1.22±0.01^{b}	1.12±0.01^{a}	1.20±0.01^{b}	1.42±0.01^{c}
Aspartic Acid	1.89±0.01^{a}	2.08±0.01^{b}	1.91±0.01^{a}	2.24±0.01^{b}
Methinonine	0.54±0.01^{a}	0.50±0.01^{a}	0.56±0.01^{a}	0.64±0.01^{b}
Glutamic Acid	2.29±0.01^{a}	2.49±0.01^{b}	2.51±0.01^{b}	2.78±0.01^{c}
Phenylalanine	0.71±0.01^{ab}	0.66±0.01^{a}	0.64±0.01^{a}	0.83±0.01^{c}
Lysine	1.68±0.01^{b}	1.63±0.01^{a}	1.72±0.01^{b}	2.24±0.01^{c}
Histidine	0.50±0.01^{bc}	0.29±0.01^{a}	0.40±0.01^{b}	0.63±0.01^{d}
Tyrosine	0.57±0.01^{ab}	0.54±0.01^{a}	0.50±0.01^{a}	0.65±0.01^{b}
Glysine	0.15±0.01^{a}	0.88±0.01^{c}	0.62±0.01^{b}	1.02±0.01^{d}
Valine	0.60±0.01^{ab}	0.64±0.01^{b}	0.53±0.01^{a}	0.78±0.01^{c}
Leucine	1.29±0.01^{b}	1.13±0.01^{a}	1.09±0.01^{a}	1.53±0.01^{c}
Isoleucine	0.37±0.01^{ab}	0.38±0.01^{ab}	0.30±0.01^{a}	0.51±0.01^{c}
Threonine	0.83±0.01^{bc}	0.76±0.01^{b}	0.66±0.01^{a}	0.92±0.01^{d}
Serine	0.86±0.01^{ab}	0.88±0.01^{b}	0.82±0.01^{a}	0.94±0.01^{c}
Proline	0.66±0.01^{a}	0.77±0.01^{b}	0.61±0.01^{a}	0.77±0.01^{b}
Ornithine	0.16±0.01^{a}	0.17±0.01^{a}	0.13±0.01^{a}	0.15±0.01^{a}
Cystine	0.15±0.01^{b}	0.20±0.01^{c}	0.08±0.01^{a}	0.13±0.01^{b}
Arginine	1.06±0.01^{b}	1.05±0.01^{b}	0.90±0.01^{a}	1.17±0.01^{c}
Total Amino Acids (g/100g)				
TAA	15.44±0.06^{a}	16.15±0.01^{b}	15.16±0.01^{a}	19.32±0.02^{c}
ΣEAA	7.57±0.01^{b}	7.04±0.01^{b}	6.80±0.01^{a}	9.24±0.01^{c}
ΣSEAA	1.56±0.01^{b}	1.34±0.01^{a}	1.30±0.01^{a}	1.80±0.01^{c}
ΣNEAA	7.87±0.05^{a}	9.12±0.01^{c}	8.37±0.01^{b}	10.08±0.01^{d}
EAA/NEAA	0.96±0.01^{c}	0.77±0.01^{a}	0.81±0.01^{b}	0.92±0.01^{c}
ΣBcAA	2.26±0.01^{b}	2.15±0.01^{b}	1.92±0.01^{a}	2.82±0.01^{c}
ΣSAA	0.69±0.01^{a}	0.70±0.01^{ab}	0.64±0.01^{a}	0.77±0.01^{bc}
ΣArAA	1.28±0.01^{b}	1.20±0.01^{a}	1.14±0.01^{a}	1.48±0.01^{c}
ΣBAA	3.24±0.01^{b}	2.97±0.01^{a}	3.02±0.01^{a}	4.04±0.01^{c}
ΣAAA	4.18±0.01^{a}	4.57±0.01^{b}	4.42±0.01^{b}	5.01±0.01^{c}
EAAI	0.88±0.01^{a}	0.85±0.01^{a}	0.83±0.01^{a}	0.97±0.01^{b}

Note: Each value means mean±standard error. Values expressed with different exponential letters on the same line are statistically different from each other ($p<0.05$).

Total amino acid values (ΣTAA) were listed as sea bream>turbot>large rainbow trout>sea bass and ΣTAA values of sea bream and turbot fillets were statistically significant ($p<0.05$). The high amino acid values of sea bream fillets were also reflected in essential (ΣEAA), semi-essential (ΣSEAA), non-essential (ΣNEAA), branched-chain (ΣBcAA), sulfur-containing (ΣSAA), aromatic (ΣArAA), basic (ΣBAA), and acidic (ΣAAA) amino acid values and essential amino acid index (ΣEAAI) values. The EAA/NEAA values were higher in large rainbow trout fillets ($p<0.05$).

Fatty Acid Composition

The fatty acid composition of cultured fish fillet of the Black Sea is presented in Table 4. The most determined saturated fatty acid in all cultured fish fillets in the Black Sea was C16:0, and the highest C16:0 was in turbot fillets, and the lowest was in large rainbow trout fillets. ($p<0.05$). The total saturated fatty acid (ΣSFA) value was highest in turbot fillets and lowest in large rainbow trout fillets, and the statistical difference between ΣSFA values of fillets was significant ($p<0.05$). C18:1n-9c value, which is the most monounsaturated fatty acid (MUFA) in fillets, was ranked as Rainbow trout>sea bream>sea bass>turbot, and the C18:1n-9c value in turbot fillets was statistically significant ($p<0.05$). The C18:1n-9c value determined at high values in fillets also affected the amount of ΣMUFA and the order of ΣMUFA in fillets was as in C18:1n-9c. The most determined polyunsaturated fatty acids in fillets were C18:2n-6c and C22:6n-3 (DHA). The C22:6n-3 (DHA) ranking was realized as turbot>large rainbow trout>sea bass>sea bream and the statistical difference between C22:6n-3 values in fillets were found to be significant ($p<0.05$). The C20:5n-3 (EPA) value was highest in the turbot fillets and lowest in the large rainbow trout ($p<0.05$). Total polyunsaturated fatty acids (ΣPUFA) in fillets were the highest turbot and the lowest sea bream fillets, and the statistical difference was significant for PU/FA values of turbot and sea bass fillets ($p<0.05$). The highest ΣOmega-3, ΣOmega-6, and ΣOmega-9 values were in turbot bass and large rainbow trout fillets, respectively. The highest omega-3/omega-6 ratio was in turbot fillets, and the highest omega-6/omega-3 ratio was in sea bass and sea bream fillets ($p<0.05$). Atherogenicity (AI) and peroxidisability (PI) index values of turbot fillets were higher than fillets of other cultured fish in the Black Sea ($p<0.05$). The thrombogenicity index (TI) values of sea bream fillets were higher than fillets of other cultured fish in the Black Sea, but the statistical difference was not significant ($p>0.05$). The highest Hypocholesterolemic/Hypercholesterolemic ratio (HH) was determined in large rainbow trout fillets and the statistical difference was found to be significant ($p<0.05$). The highest EPA+DHA value was in turbot fillets ($p<0.05$), while the highest EPA/DHA ratio was determined in sea bass fillets ($p<0.05$).

Fillet Color

Table 5 shows the L*, a*, b*, C* and Hue values in three different measurement regions (1st location: between behind of the operculum; 2nd location: under the dorsal fin; and 3rd location: front of caudal fin) of large rainbow trout, turbot, sea bass, and sea bream fillets cultured in the Black Sea. The highest L* (lightness) values in all measurement regions were determined in turbot fillets ($p<0.05$). The highest a* (redness), b* (yellowness), C* (chroma), and Hue (true color) values were determined in large rainbow trout fillets at all measurement regions. The average L* values of the fillets were in the order of turbot>large rainbow trout>sea bream>sea bass, and the L* values of the turbot and large rainbow trout fillets were to be statistically significant ($p<0.05$).

Discussion

A deeper insight into the biochemical, amino acid, and fatty acid composition and color parameters of four culture fish species (large rainbow trout, turbot, sea bass, and sea bream) from the Black Sea region, was given through this study. Although the market weight of cultured fish is determined under the name of "portion weight" (250-350 g), consumer preferences play an important role in the weights of fish offered to the market. For example, rainbow trout is sold in 1kg apart from its portion weight or in the 3-5 kg range called "Turkish salmon", and sea bass and sea bream are sold over 500g in order to be similar to the wild type.

Carcass yields (CY) differ between species (Table 1). Our results indicate that large rainbow trout has the largest CY of the species studied at almost 44.23±1.66% of the body weight, compared to turbot fillets which were the lowest at 27.37±1.4% of body weight ($p<0.05$). Malcorps et al. (2021) reported that CY could increase or decrease only depending on the fish species. So much so that while the CY of sea bass and rainbow trout with a fusiform body shape approaches 50% (Baki et al., 2015; Kaya Öztürk et al., 2019; Tarricone et al., 2022), this rate varies between 30% and 50% in large-headed sea bream (Kaya Öztürk et al., 2020), and decreases to 20% in a flat-bodied turbot (Malcorps et al., 2021).

Table 4. Fatty acid composition of cultured fish fillets in the Black Sea (%)

Fatty Acid	Large Rainbow Trout	Turbot	Sea Bass	Sea Bream
C12:0	0.08±0.01^{a}	0.09±0.01^{a}	0.06±0.01^{a}	0.09±0.01^{a}
C13:0	0.02±0.01^{a}	0.07±0.01^{b}	0.02±0.01^{a}	0.02±0.01^{a}
C14:0	2.91±0.02^{a}	5.31±0.11^{c}	3.23±0.06^{b}	3.46±0.02^{b}
C15:0	0.41±0.01^{a}	1.10±0.01^{c}	0.50±0.01^{ab}	0.48±0.01^{a}
C16:0	12.31±0.09^{a}	13.80±0.21^{c}	12.77±0.10^{b}	12.85±0.04^{b}
C17:0	0.47±0.01^{a}	0.79±0.01^{c}	0.63±0.02^{b}	0.61±0.01^{b}
C18:0	6.54±0.08^{b}	4.60±0.01^{a}	6.78±0.08^{b}	7.54±0.08^{c}
C20:0	0.74±0.03^{a}	0.78±0.01^{a}	0.87±0.01^{b}	0.96±0.01^{c}
C21:0	0.02±0.01^{a}	0.06±0.01^{b}	0.02±0.01^{a}	0.02±0.01^{a}
C22:0	0.49±0.01^{a}	0.64±0.01^{c}	0.41±0.01^{a}	0.58±0.04^{b}
C23:0	0.04±0.01^{a}	0.04±0.01^{a}	0.06±0.01^{a}	0.15±0.05^{b}
C24:0	0.08±0.01^{b}	0.07±0.01^{b}	0.02±0.01^{a}	0.04±0.01^{a}
ΣSFA	24.11±0.24^{a}	27.35±0.29^{c}	25.37±0.26^{ab}	26.77±0.15^{b}
C14:1	0.17±0.01^{a}	0.42±0.01^{c}	0.21±0.01^{a}	0.30±0.01^{b}
C15:1	0.06±0.01^{a}	0.17±0.01^{b}	0.06±0.01^{a}	0.07±0.01^{a}
C16:1	0.37±0.01^{a}	0.98±0.02^{c}	0.57±0.02^{b}	0.60±0.01^{b}
C17:1	0.48±0.01^{a}	0.84±0.02^{c}	0.60±0.01^{b}	0.68±0.01^{b}
C18:1n-9c	25.26±0.42^{b}	17.45±0.22^{a}	24.99±0.17^{b}	25.02±0.06^{b}
C18:1n-9t	1.16±0.08^{a}	3.06±0.09^{c}	2.50±0.03^{b}	2.24±0.03^{b}
C20:1n-9c	4.57±0.19^{c}	2.25±0.05^{b}	1.25±0.03^{a}	1.20±0.01^{a}
C22:1n-9	3.87±0.05^{c}	2.45±0.04^{a}	2.82±0.02^{b}	3.09±0.01^{bc}
C24:1	1.16±0.01^{a}	1.08±0.03^{a}	1.10±0.01^{a}	1.76±0.01^{b}
ΣMUFA	37.11±0.37^{b}	28.71±0.03^{a}	34.11±0.20^{b}	34.94±0.06^{b}
C18:2n-6t	0.44±0.01^{b}	0.11±0.01^{a}	0.64±0.02^{c}	0.64±0.01^{c}
C18:2n-6c	12.60±0.19^{a}	13.08±0.11^{b}	13.77±0.06^{b}	12.88±0.03^{a}
C18:3n-3	6.01±0.09^{c}	3.02±0.07^{a}	6.04±0.04^{c}	5.81±0.01^{b}
C18:3n-6	0.35±0.01^{a}	0.31±0.01^{a}	0.62±0.02^{b}	0.60±0.01^{b}
C20:2	3.03±0.04^{c}	1.99±0.04^{a}	2.79±0.01^{bc}	2.43±0.01^{b}
C20:3n-3	1.57±0.02^{c}	0.52±0.01^{a}	1.02±0.02^{b}	1.45±0.01^{c}
C20:3n-6	0.35±0.01^{b}	0.19±0.01^{a}	0.32±0.01^{b}	0.44±0.03^{c}
C20:4n-6	1.69±0.02^{a}	1.64±0.03^{a}	1.69±0.02^{a}	1.67±0.02^{a}
C20:5n-3	3.81±0.05^{a}	7.31±0.01^{d}	5.28±0.05^{c}	4.31±0.03^{b}
C22:2	0.09±0.03^{a}	0.08±0.01^{a}	0.08±0.01^{a}	0.14±0.01^{a}
C22:6n-3	9.83±0.14^{c}	15.61±0.02^{d}	8.26±0.14^{b}	7.87±0.02^{a}
ΣPUFA	39.77±0.52^{a}	43.86±0.29^{b}	40.50±0.06^{ab}	38.23±0.07^{a}
ΣOmega-3	21.22±0.30^{a}	26.46±0.10^{b}	20.60±0.15^{a}	19.44±0.04^{a}
ΣOmega-6	15.43±0.21^{a}	15.33±0.16^{a}	17.03±0.08^{c}	16.22±0.05^{b}
ΣOmega-9	34.87±0.37^{c}	25.21±0.05^{a}	31.56±0.23^{b}	31.54±0.08^{b}
n3/n6	1.38±0.01^{b}	1.73±0.01^{c}	1.21±0.01^{a}	1.20±0.01^{a}
n6/n3	0.73±0.01^{b}	0.58±0.01^{a}	0.83±0.01^{c}	0.83±0.01^{c}
EPA/DHA	0.39±0.01^{a}	0.47±0.01^{b}	0.64±0.01^{d}	0.55±0.01^{c}
EPA+DHA	13.64±0.19^{b}	22.92±0.03^{c}	13.54±0.18^{b}	12.18±0.03^{a}
AI	0.32±0.01^{a}	0.50±0.01^{b}	0.36±0.01^{a}	0.38±0.01^{a}
TI	0.24±0.01^{a}	0.23±0.01^{a}	0.26±0.01^{a}	0.28±0.01^{a}
PUFA/SFA	1.65±0.02	1.60±0.03^{b}	1.60±0.02^{b}	1.43±0.01^{a}
HH	3.52±0.05^{b}	2.89±0.05^{a}	3.42±0.05^{b}	3.21±0.02^{a}
PI	138.01±1.94^{b}	197.87±0.59^{c}	135.90±1.21^{b}	125.15±0.30^{a}

Note: Each value means mean±standard error. Values expressed with different exponential letters on the same line are statistically different from each other ($p<0.05$).

Table 5. The L*, a*, b*, C* and Hue values of cultured fish fillets in the Black Sea

Values	Large Rainbow Trout	Turbot	Sea Bass	Sea Bream
1st location (The behind of the operculum)				
L*	50.88±2.18^{by}	65.85±1.93^{cx}	43.37±0.90^{ax}	46.90±1.33^{ax}
a*	10.00±2.22^{bx}	0.98±0.94^{ax}	0.79±0.20^{ax}	0.72±0.80^{ax}
b*	16.07±1.41^{dx}	4.71±1.24^{cx}	-0.35±0.50^{ax}	0.33±0.67^{bx}
C*	19.47±1.99^{dx}	5.22±1.26^{cy}	1.45±0.25^{ax}	2.67±0.74^{bx}
Hue	1.05±0.10^{cx}	0.01±0.51^{ax}	0.31±0.45^{bx}	0.48±0.24^{bx}
2nd location (Under the dorsal fin)				
L*	48.65±0.70^{ax}	65.70±0.81^{bx}	45.66±1.14^{ax}	46.65±1.15^{ax}
a*	12.27±1.10^{cx}	0.93±0.66^{ax}	3.68±0.62^{by}	3.69±0.98^{by}
b*	18.18±0.96^{dy}	4.07±0.83^{cx}	2.75±0.72^{by}	1.34±0.46^{ay}
C*	22.39±1.27^{cy}	4.62±0.94^{bx}	4.62±0.50^{by}	3.88±0.61^{ay}
Hue	1.02±0.03^{dx}	-0.13±0.22^{ax}	0.51±0.49^{cy}	0.27±0.08^{bx}
3rd location (Front the caudal fin)				
L*	53.62±3.77^{ay}	62.48±0.95^{bx}	51.40±0.82^{ay}	49.61±1.23^{ax}
a*	11.34±2.44^{dx}	0.71±0.58^{ax}	4.25±0.65^{by}	6.18±1.59^{cz}
b*	18.14±0.92^{cy}	5.01±1.09^{by}	3.41±0.57^{ay}	2.77±1.18^{az}
C*	21.99±1.75^{bxy}	5.17±1.14^{ay}	5.52±0.69^{ay}	6.80±1.94^{az}
Hue	1.05±0.09^{cx}	0.49±0.57^{aby}	0.68±0.10^{by}	0.38±0.05^{ax}
Average				
L*	51.05±1.60^{b}	64.67±1.10^{c}	46.81±1.10^{a}	47.72±0.76^{a}
a*	11.20±1.27^{c}	0.88±0.44^{a}	1.98±0.52^{b}	2.58±0.99^{b}
b*	17.46±0.69^{c}	4.60±0.54^{b}	1.08±0.55^{a}	1.14±0.57^{a}
C*	21.28±1.08^{c}	5.00±0.56^{c}	2.74±0.61^{a}	3.68±0.91^{b}
Hue	1.04±0.05^{b}	0.13±0.30^{a}	0.33±0.19^{a}	0.39±0.08^{a}

Note: Each value represents the mean±standard error. Values expressed with different exponential letters on the same line are statistically different from each other ($p<0.05$).

a, b: The differences between the means with different letters on the same line within the group are statistically significant ($p<0.05$).

x, y: The differences between the means with different letters in the same column in different regions are statistically significant ($p<0.05$).

The average a* and Hue values were the highest in large rainbow trout fillets and the lowest in turbot fillets ($p<0.05$). The average b* and C* values were the highest in the large rainbow trout fillets and the lowest in the sea bass fillets, and the difference was statistically significant ($p<0.05$).

Analysis of the biochemical composition showed that the turbot fillets had a statistically significant ($p<0.05$) lower dry matter (DM), crude fat (CF), crude ash (CA), and crude protein (CP) contents than analyzed other fish fillets. In addition, the biochemical composition values of turbot fillets were lower than previous studies (Manthey-Karl et al., 2016; Hernandez-Urcera et al., 2017). In the remaining three fish species fillets, the CP and CF values were higher than those presented in earlier studies values (Regost et al., 2001; Poontawee et al., 2007; Davidson et al., 2014; Baki et al., 2015; Kaya Öztürk et al., 2019, 2020; Tarricone et al., 2022). The biochemical composition of fish fillets did not correlate with the composition of the feed which the fish were fed ($r=0.15$, $p=0.714$); (Supplementary file Table S2), because it is not the only parameter that affects the biochemical composition of a fish species. In general, the biochemical compositions of fish vary with the season of cultivation (Petrović et al., 2015). Because fish are ectothermic poikilotherms, the CF in a certain period of the year can be attributed to the ongoing physiological process of conserving the fat stock, which occurs in autumn after intense feeding, or the process of spending the fat stock, which occurs during winter. In early summer, when environmental conditions change, primarily as an increase in temperature, the fish metabolism accelerates and the energy taken from food is used for fish growth. In addition, Grigorakis (2007) reported that a variety of variables, including age, sex, and environmental variables like temperature, salinity, etc., may have an impact on biochemical composition. Therefore, in this study, although the sea bass and sea bream were fed the same type of feed and in the same environmental condition, their biochemical composition contents differed significantly.

Adequate dietary amino acid supply is critical for animal and human health, growth, development, and survival (Wu, 2009). Amino acids have traditionally been classed as nutritionally essential (EAA) or non-essential (NEAA) for mammals, birds, and fish based on growth or nitrogen balance (Le Plénier et al., 2012). When the results were expressed per 100 g of product, the ΣEAA ranged between 6.80±0.01 g in sea bass fillet to 9.24±0.01 g in sea bream fillet. Although they were fed the same diets, the differences in the amino acid contents between sea bass and bream and were statistically significant. The EAA composition measured for the cultured fish fillets in the present study and generally matched previously reported fillets' EAA values, with lysine and leucine, consistently being dominant in all species (Kaushik, 1998; Peres & Oliva Teles, 2008; Sanchez-Lozano et al., 2011; Baki et al., 2015; Yıldız & Ofori-Mensah 2017; Colombo & Mazal, 2020). The EAA requirement for an adult human weighing 70 kg is about 5.6g per day (Gawedzki, 1997). The EAA results in the present study indicated that 100g of cultured fish from the Black Sea, met the daily requirement for EAA. In addition, Wang & Han (2017) reported that the EAA content and ratio is an essential factor for learning protein quality. According to FAO/WHO (1973), the ratio of EAA to ΣTAA should be at least 40% in a quality protein. In the current study, the EAA/TAA ratios of large rainbow trout, turbot, sea bass, and sea bream fillets were determined as 49.02, 43.59, 44.85, and 47.82%, respectively, and the protein quality of all fillets was suitable for human consumption according to FAO/WHO (1973).

The fatty acid composition data demonstrate that C18:1n-9 was the most significantly represented fatty acid in four species studied, followed by C18:2n-6 and C16:0. The results of this study are similar to previous studies that demonstrated an increase in C:18 fatty acids, such as C18:1n-9, C18:2n-6, and C18:3n-3, in cultured fish, in response to the use of vegetable oils in their feed (Benedito-Palos et al., 2009; Strobel et al., 2012). Among the unsaturated fatty acids, 18:1n-9 and C18:2n-6 contribute the most to the enrichment of aromatic components (Elmore et al., 1999) and are regarded as having high nutritional value since they protect against cardiovascular disease (Hornstra, 1999). There were statistically significant differences in the fatty acid content of the fillets of the fish species studied ($p<0.05$). The value of SFA (C13:0, C14:0, C15:0, C16:0, C17:0; C21:0 and C22:0) was the highest in the turbot fillets and this result was similar to Manthey-Karl et al. (2016) and Pleadin et al. (2017)'s study. The large rainbow trout, sea bass, and sea bream fillets had a significantly higher value of MUFA than the turbot fillets, which is attributable to their C18:1n-9 contents. The reason for the high oleic acid values in fish fillets is generally explained by over-adding vegetable oil sources in fish diets (Francis et al., 2007a, 2007b; Pettersson et al., 2010). In this study, the presence of high levels of C18:1n-9 in the diets of large rainbow trout, sea bass and sea bream (Supplementary file Table S2) supports the aforementioned studies. A significantly lower proportion of C18 PUFAs (C18:2n-6t, C18:3n-3, C18:3n-6) was found in the turbot fillets (except C18:2n-6c). In previous studies, the mentioned fatty acids were at low values in turbot fillets (Manthey-Karl et al., 2016; Pleadin et al., 2017). The fillet of turbot analyzed in this study contained less SFA and MUFA, and at the same time, more omega-3 and more PUFA than previously reported levels, resulting in a more favorable omega-3/omega-6 ratio than obtained by other researchers (Sérot et al., 1998; Pleadin et al., 2017). Many studies have demonstrated that fish consumption protects against coronary heart disease (He, 2009; Mozaffarian & Wu, 2011; Tacon et al., 2020). Simopoulos (2002) claimed that the omega-3/omega-6 ratio is a reliable index for comparing the relative nutritional values of species. High omega-3/omega-6 ratios are crucial for human health because they can reduce or prevent fetal programming and cardiovascular disease in adults (Marangoni et al., 2020; Shrestha et al., 2020). According to Sargent (1997) although the optimum omega-3/omega-6 ratio should be 1:5, Testi et al. (2006) reported that this ratio should be a minimum 1:1. In this study, the omega-3/omega-6 ratio of fish cultured in the Black Sea (the lowest sea bream, the highest turbot fillet, see Table 4) was higher than 1:1. It is thought that this result is an indicator of the environmental condition and feed quality in aquaculture. The consumption of fish and the intake of n-3 long-chain PUFAs are advised in distinct ways (especially EPA and DHA). While The American Heart Association (2022) recommends eating two servings of fish (especially oily fish such as salmon, and rainbow trout) twice a week to meet the dietary needs of EPA and DHA for human nutrition, the German Nutrition Association recommends a smaller once-a-week fat content portions of fatty fish (70 g) and larger portions of lean fish (80-150 g) (Berglaiter, 2012). Generally, most of official organizations recommend two meals of fish each week (around 140-240 g per meal) (Comi et al., 2022). This recommendation, would deliver about 500 mg of combined EPA and DHA per day, which is the amount that the majority of nations and organizations advise for optimum general health and decreased cardiovascular risk. Nevertheless, the European Food Safety

Authority (EFSA) has set a minimum daily value of 250 mg of EPA and DHA for adults (EFSA, 2009). Therefore, approximately 55, 92, 54, and 49g of large rainbow trout, turbot, sea bass, and sea bream, respectively must be ingested daily in order to meet the lowest-level EFSA recommendation.

Dietary fats are generally fatty acids that may play positive or negative roles in preventing and treating diseases. In nature, fatty acids occur in the form of mixtures of SFA, MUFA and PUFA, so their nutritional and/or medicinal values must be determined (Chen & Liu, 2020). The, IA, IT and HH (Ulbritcht & Southgate, 1991) are the most commonly used to assess the composition of fatty acids as they outline significant implications and provide clear evidence. Pleadin et al. (2017) reported that lipids with AI<1 and TI<1 are beneficial to human health. According to Tonial et al. (2014), MUFA and PUFA have more significant health advantages since they lower the risk of cardiovascular disease. The AI and TI values determined in the present study were lower than 1 and the statistical difference was not significant except for the AI value of the turbot fillet. In many studies, the AI and TI values of the fish fillets are lower than 1 and are in the similar value range with the data in this study (Cieślik et al., 2017; Khalili Tilami et al., 2018; Tarricone et al., 2022). Based on the above-mentioned discussion, it was decided to use HH, another nutritional quality measure, to learn more about how fatty acids affect cholesterol levels. It is ideal if the HH index has a greater value, such as >3 (Santos-Silva et al., 2002; Testi et al., 2006). In this investigation, the HH values varied from 2.89±0.05 in the turbot fillets to 3.52±0.05 in the large rainbow trout fillets. Because these three species had smaller amounts of SFA than turbot fillets, the HH ratios for large rainbow trout, sea bass, and sea bream were much greater than those for turbot.

Color is a significant attribute of fish freshness quality and is also used as an indirect estimate of chemical components and sensory characteristics of food (Cheng et al., 2015). Cultured sea bass and sea bream fillets were darker than turbot and large rainbow trout fillets, regardless of measuring regions, as can be observed by the significantly lower L* values ($p<0.05$) (Table 5). In some studies, it has been stated that the L* value determined in fish fillets is related to the moisture content of the fish fillets (Hernández et al., 2009; Fuentes et al., 2010), but this relationship was not found in this study. The a* value in large rainbow trout fillets was significantly higher than the other three cultured fish fillets and was statistically significant ($p<0.05$). Because sea bass, sea bream, and turbot are white-fleshed, it is normal for the a* value to be high for large rainbow fillets. The average a* value of large rainbow trout fillets was 11.20±1.27, which was lower than the studies on rainbow trout color parameters (Regost et al., 2001; Poontawee et al., 2007; Kaya Öztürk et al., 2019). The redness of the fillet in Salmonid species is an important quality parameter that gives a different image to this species. In previous studies, this difference in a* value reported that the redness values of fillet depend on the amount of carotene in fish feeds, pigment types, lipid source and level (Marty-Mahé et al., 2004; Lerfall et al., 2017).

Conclusion

Globally, aquaculture continues to be one of the fastest-growing food-producing sectors. However, preconceptions about the nutritional values of farmed fish influence consumption. Therefore, fish consumption is very important for balanced nutrition and minimizing health problems. This study established that cultivated fish from the Black Sea have excellent nutritional values, including high amounts of unsaturated fatty acids and the appropriate quantity of essential amino acids, and that they are of good quality, nutritious, and beneficial for human consumption.

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Compliance With Ethical Standards

Conflict of Interest

The author declares that has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical Approval

Not applicable. The fish were sampled by the operating personnel while they were harvested, therefore this manuscript does not need ethical approval.

Data Availability

All data generated or analyzed during this study are included in this published article.

Supplementary Materials

Supplementary data to this article can be found online at https://doi.org/10.33714/masteb.1195335

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