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Environmental effects on nutrient composition of Turkish Salmon (*Oncorhynchus mykiss*): a comparison between marine and reservoir systems

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ORIGINAL ARTICLE

Abstract

This study investigated the nutritional composition of trout (*Oncorhynchus mykiss*), referred to as Turkish salmon, cultured in marine and dam lake environments across winter and summer seasons. The nutritional composition of rainbow trout showed notable seasonal and environmental variation, with protein remaining relatively stable (18.50–19.36%), while lipid content ranged from 4.10% (winter, dam lake) to 11.73% (summer, dam lake) and from 10.14% to 8.70% in marine samples, accompanied by an inverse relationship with moisture (68.19–74.62%), and ash content varied slightly between 1.35% and 1.71%. Seasonal and habitat-related variations were observed in proximate composition, with protein content peaking in summer-harvested fish and lipid levels notably lower in dam lake winter samples, showing an inverse relationship with moisture. Fatty acid analysis identified palmitic acid as the dominant saturated fatty acid and oleic acid as the main monounsaturated fatty acid. Among amino acids, L-glycine and other essential amino acids were abundant, while potassium and phosphorus predominated in the mineral profiles, and iron was consistently low. Vitamin E and niacinamide were the most prevalent fat- and water-soluble vitamins, respectively. These results demonstrate that Turkish salmon possess high nutritional value, emphasizing the influence of seasonal and environmental factors, and provide critical insights for optimizing aquaculture practices, harvest timing, and dietary recommendations.

Keywords: aquaculture, nutrient profile, *Oncorhynchus mykiss*, rainbow trout

Introduction

Fish is one of the most important foods in the human diet because of its high nutritional content. It is an important protein source, particularly one with high biological value (Sargent *et al.,* 2002). In addition to protein, fish contains essential macronutrients such as lipids and small amounts of carbohydrates, as well as micronutrients, including vitamins and minerals (Balami *et al.,* 2019). According to the Food and Agriculture Organization (FAO), fish proteins are highly digestible and contribute significantly to human nutrition (FAO, 2020). The amount of protein in fish meat varies depending on the species. It is particularly important that fish proteins contain essential amino acids in a well-balanced ratio, as this determines their biological value (Hardy *et al*., 2022).

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In addition, fish meat is also rich in both water-soluble B vitamins and fat-soluble vitamins, especially in oily fish species (Bremner, 2002). In addition, seafood is also very important, as it contains minerals such as iodine, selenium, magnesium, zinc, and calcium, which are necessary for human health (Varlık *et al*., 2011). Omega-3 fatty acids derived from fish, especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), play a crucial role in metabolic processes (Mendivil, 2021). Oily fish, such as salmon, are considered one of the best dietary sources of EPA and DHA (Glencross *et al.,* 2025).

Scientific evidence consistently identifies fish as a key component of a balanced diet. Regular consumption supports growth, improves overall health, and reduces the risk of cardiovascular diseases. It also contributes to the prevention of rickets and supports cognitive development in children. In addition, bioactive compounds in fish have been associated with protective effects against cancer and neurodegenerative diseases, such as Alzheimer's disease (Ali *et al.,* 2022).

The most important characteristic that distinguishes migratory salmonid fish species (*Salmo* spp., *Oncorhynchus* spp., and *Salvelinus* spp.) from other fish, and the most important quality indicator that increases their economic value, is that their flesh is pinkish-red (Rahman *et al*. 2016). This coloration is due to naturally occurring carotenoids, particularly astaxanthin. Flesh color is also considered an indicator of quality, including freshness and flavor (Oehlenschläger and Ostermeyer 2024). Therefore, the inclusion of carotenoids, such as astaxanthin, in the feed to enhance flesh pigmentation increases the marketability of farmed fish and raises their commercial value (Li *et al.,* 2023, Elbahnaswy, and Elshopakey, 2024).

Along with the growth of marine aquaculture along Türkiye's Black Sea coast, cage farming of large rainbow trout, referred to as Turkish salmon, is becoming a major component of the economy (FAO, 2022). The term "Turkish salmon" is widely used as a commercial designation; however, it does not refer to a distinct taxonomic species. Instead, it represents a large-bodied form of rainbow trout (*Oncorhynchus mykiss*), which is one of the most extensively farmed aquaculture species in the country and globally. The Black Sea Region, with particular emphasis on Trabzon, constitutes the central hub for Turkish salmon aquaculture. In 2025, Turkish salmon production and exports continued their rapid growth, with export volumes reaching approximately 79 thousand metric tons and generating over 520 million USD in revenue. Türkiye's aquaculture sector also achieved a historic milestone, with total fisheries production exceeding 1.02 million tons, of which around 600 thousand tons originated from aquaculture. The demand for Turkish salmon has expanded significantly across international markets, particularly in countries such as Russia, Vietnam, and Belarus, reflecting its increasing competitiveness in the global seafood trade (DKİB, 2025; Yumaklı, 2026). The species designated as "Turkish salmon," which is the rainbow trout (*Oncorhynchus mykiss*), has become a sought-after commodity in the international market owing to its elevated nutritional profile and superior quality. This study aims to compare the nutritional composition of trout (*Oncorhynchus mykiss*), known as Turkish salmon in Türkiye, cultured in marine and dam lake environments (the Black Sea and Kürtün Dam Lake) in two different seasons (summer and winter).

Material and Method

Sampling

Rainbow trout (*Oncorhynchus mykiss*) samples farmed in the Black Sea (Yomra–Trabzon) and the Kürtün Dam Lake (northwestern Türkiye) were collected for analysis. Average water temperatures in winter and summer varied between 10–25 ± 1°C for the Black Sea and 8–15 ± 1°C for Kürtün Dam Lake, respectively. Seawater salinity in the Black Sea was measured at approximately 17–18 parts per thousand. The mean ± SD length and weight of the samples collected during the summer period were 46.5 ± 2 cm and 1300 ± 100 g for sea-farmed trout, and 41.5 ± 2 cm and 1050 ± 100 g for dam-farmed trout. During the winter period, the mean ± SD length and weight were 38 ± 2 cm and 950 ± 50 g for sea-farmed trout, and 36 ± 2 cm and 745 ± 20 g for dam-farmed trout. Approximately 20 fish were used for both the sea and the dam lake in different seasons. A total of 80 fish were used. Each fish was filleted without the skin, and the muscle tissue was homogenized. The homogenized fish meat was used in the analyses.

Nutritional composition analysis

The rainbow trout (*Oncorhynchus mykiss*) samples were analyzed in triplicate for nutritional composition. The total lipid content (% ww) of 5 g of homogenized raw edible portions of fish meat samples was determined by the chloroform/methanol extraction gravimetric method described by Bligh and Dyer (1959). The moisture content (% ww) of 3–5 g of homogenized raw edible portions of fish meat samples was determined for all samples by drying for 6 hours at 105°C, as described in the official AOAC method 934.01 (2006a). The ash content (% ww) of the moisture-free samples was determined using the official AOAC method 950.46 by ashing for 4–6 hours at 550°C (AOAC, 1990). The total crude protein (% ww)

of 1 g of homogenized raw edible portions of fish meat samples was analyzed using the Kjeldahl method 984.13 (AOAC, 2006b).

Fatty acids analysis

The methyl esters of lipids from the samples were prepared by trans-methylation using gas chromatography–flame ionization detection (GC-FID, Agilent 7820 Model, Waldbronn, Germany) according to the method described by Ichihara *et al*. (1996). Extracted oil (25 mg) was dissolved in 2 mL of isooctane (≥99.8%, Merck, Darmstadt, Germany), followed by the addition of 4 mL of 2 M KOH in methanol (≥85.0%, Merck, Darmstadt, Germany). The tube was then vortexed for 2 min at room temperature. Separation into methyl esters was performed in triplicate for each sample. After centrifugation at 4000 rpm for 10 min, the isooctane layer was collected for gas chromatography (GC) analysis.

Gas chromatography (GC) conditions

The fatty acid methyl esters were analyzed using gas chromatography (Agilent Technologies, model 7820) equipped with a flame ionization detector (FID) and fitted with an HP-88 capillary column (60 m × 0.25 mm × 0.25 μm thickness). Helium was used as the carrier gas at a constant pressure of 16 psi. The injection port was maintained at 220 °C, and the sample was injected in split mode with a split ratio of 50:1. During the analysis, the detector temperature was 280 °C. The column temperature was initially set at 175 °C, then programmed at 3 °C/min to 220 °C, ramped at 1 °C/min to 220 °C, and held for 10 min. The total running time was 26 min. Helium was used as the makeup gas at a constant flow of 40 mL/min, and hydrogen and dry air were used as detector gases. Identification of fatty acids was carried out by comparing the relative retention times of sample fatty acid methyl ester (FAME) peaks with those obtained for fatty acid standards (Supelco 37 FAME mix, high purity, Sigma-Aldrich). The results were expressed as a percentage of total fatty acid methyl esters.

Amino acid analysis

Amino acid analysis was performed at the Technology Research and Development Application and Research Center (TUTAGEM) laboratory of Trakya University (Türkiye). The analysis was conducted using an LC system (Agilent Technologies, Waldbronn, Germany). MS/MS analyses were carried out on an Agilent 6460 triple quadrupole LC-MS equipped with an electrospray ionization interface. A 1 g sample was placed in a Falcon tube, and 20 mL of extra-pure water was added. After an ultrasonic bath, the sample was sonicated for 10 min at 50°C. The samples were centrifuged for 5 min at 13,500 rpm. The samples were prepared as a mixture of 50 μL of the supernatant, 50 μL of internal standard (ISTD), and 700 μL of solvent (mobile phase A: methanol:acetonitrile, v:v:v, 5:15:15). The mixture was then injected into the LC-MS/MS system, and analysis was performed (Bayram *et al*., 2021). LC-MS/MS instrument conditions are shown in Table S1.

Mineral substance analysis

Mineral substance analysis was carried out at the Technology Research and Development Application and Research Center (TUTAGEM) laboratory of Trakya University (Türkiye). Elemental analysis was performed using inductively coupled plasma mass spectrometry (ICP-MS) following the U.S. EPA Method 200.8 (1994) guidelines. Samples were first digested using a microwave-assisted acid digestion procedure with a mixture of nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) to ensure complete dissolution of the matrix. The digested solutions were then diluted with ultrapure water to appropriate concentrations for ICP-MS analysis. Calibration standards were prepared from certified multi-element stock solutions covering the expected concentration ranges. Element concentrations were quantified by comparing sample signal intensities to the calibration curve, with limits of detection and quantification established according to the method.

Sample preparation

HNO_3 (10 mL) (≥90.0%, Sigma-Aldrich, Darmstadt, Germany) was added to 0.5 g of the weighed fish sample, and organic compounds were removed by performing an ashing process in a CEM-brand microwave system, ensuring that inorganic compounds passed into the acid solution. Subsequently, dilution procedures were performed, and analysis was carried out using an Agilent 7700× ICP-MS device, with element concentrations in the sample reported in mg/kg.

Vitamin analysis

Vitamin analyses were carried out at the Technology Research and Development Application and Research Center (TUTAGEM) laboratory of Trakya University (Türkiye). Vitamin analysis was performed by modifying the application note published by Zhao and Osborn (2021). Device conditions are shown in Table S2.

Sample preparation for water soluble vitamins (WSV)

Extraction solution (20 mL) (UPW + 1% formic acid (≥85.0%, Sigma-Aldrich, Darmstadt, Germany)) was added to 1 g of the sample. After vortexing for 30 seconds, the sample was incubated in an ultrasonic bath at 45°C for 10 minutes. It was then centrifuged at 9000 rpm for 5 minutes, and the clear filtrate was transferred into insert glass vials for injection. Water-soluble vitamin analyses were performed using an Agilent 1260 Infinity liquid chromatography system coupled with an Agilent 6460 triple quadrupole MS/MS system (Jet Stream electrospray ion source).

Sample preparation for fat soluble vitamins (FSV)

Extraction solution (20 mL; MeOH (≥99.9%, Sigma-Aldrich, Darmstadt, Germany) + 1% formic acid (≥85.0%, Sigma-Aldrich, Darmstadt, Germany)) was added to 1 g of the sample. The mixture was vortexed for 30 seconds, incubated in an ultrasonic bath at 45°C for 10 minutes, and centrifuged at 9000 rpm for 5 minutes. The clear filtrate was then transferred into insert glass vials for injection. Fat-soluble vitamin analyses were performed using an Agilent 1260 Infinity liquid chromatography system coupled with an Agilent 6460 triple quadrupole MS/MS system (Jet Stream electrospray ion source).

Statistical analysis

All experiments were carried out in triplicate, and the results were expressed as mean ± standard deviation. Significance levels were defined as $p < 0.05$. Comparisons between groups were performed by analysis of variance (ANOVA), followed by Tukey's multiple range test ($p < 0.05$), using SPSS software (Version 21, SPSS Inc., Chicago, IL, USA). The normality of the data distribution was assessed using the Shapiro–Wilk test prior to performing parametric statistical analyses.

Results and Discussion

Nutrient contents of rainbow trout

The results of the seasonal nutritional composition analysis of rainbow trout samples used in the study are presented in Table 1. The protein content of the samples collected from the dam during the summer period was lower than that of the samples taken from the Black Sea during the winter period. No significant differences were observed in terms of protein content, either with respect to the farming location or the seasons ($p > 0.05$).

Previous studies have reported comparable crude protein levels in salmonids under different rearing conditions. For example, Keskin *et al.* (2022) found similar protein contents between rainbow trout cultured in the Central Black Sea Region and market Atlantic salmon. Likewise, Korkmaz and Kırkağaç (2008) reported crude protein contents of 20.33% and 19.59% for trout reared in freshwater ponds and marine cages, respectively. Colombo and Mazal (2020) observed crude protein contents of 20.4% and 19.1% in farmed and organic Atlantic salmon, respectively. The values in the present study align closely with these reports, indicating a relatively stable protein composition across production systems. Minor variations may reflect differences in fish size, developmental stage, season, feeding regime, or environmental conditions.

The crude lipid content exhibited significant variation depending on both season and rearing environment ($p < 0.05$). Specifically, lipid levels were higher in dam-reared rainbow trout during the summer, whereas in winter, higher lipid content was observed in sea-reared individuals. The relatively lower lipid content detected in the dam winter samples may be attributed to the incomplete physiological development of these fish, as they had not yet reached optimal harvest size. In contrast, the elevated lipid levels observed in sea-reared trout during winter, compared to summer, may reflect adaptive metabolic responses to colder water

Table 1. Seasonal nutritional composition analysis results of rainbow trout groups.

	Protein (%)		Lipid (%)		Ash (%)		Moisture (%)	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Marine	18.65 ± 0.91^{Aa}	19.16 ± 0.47^{Aa}	10.14 ± 1.93^{Aa}	8.70 ± 0.44^{Bb}	1.53 ± 0.12^{Ba}	1.35 ± 0.13^{Ab}	69.68 ± 0.14^{Ba}	70.62 ± 0.97^{Aa}
Dam lake	19.36 ± 0.74^{Aa}	18.50 ± 0.43^{Aa}	4.10 ± 0.54^{Bb}	11.73 ± 0.52^{Aa}	1.71 ± 0.09^{Aa}	1.45 ± 0.09^{Ab}	74.62 ± 0.21^{Aa}	68.19 ± 0.79^{Bb}

Data are presented as mean ± standard deviation (n = 3). Superscript letters indicate statistically significant differences at $P < 0.05$: uppercase letters (A, B) denote differences between seasons within the same rearing environment, while lowercase letters (a, b) denote differences between rearing environments within the same season.

temperatures, where increased lipid deposition serves as an energy reserve and contributes to maintaining cellular membrane functionality (Lee *et al*., 2022). These findings are consistent with previous studies. For instance, Erdem *et al*. (2020) reported a lipid content of 9.29% in Atlantic salmon, while Nenciu *et al*. (2022) demonstrated that trout reared in the Black Sea exhibited higher total lipid levels (13.53%) compared to freshwater samples (7.04%). Similarly, Keskin *et al*. (2022) determined crude lipid contents of 6.30% in Turkish salmon and 8.57% in Atlantic salmon. When evaluated in the context of the existing literature, the results of the present study fall within the reported range of lipid content for salmonid species, although variations are evident.

Such variability in lipid content is well documented and can be attributed to a complex interplay of biological and environmental factors, including species, age, sex, genetic background, habitat or rearing conditions, seasonal fluctuations, feeding regime, and water quality parameters (Erdem, 2006). In particular, diet composition, growth stage, and seasonal changes are recognized as key determinants influencing lipid accumulation in fish muscle. Therefore, the lower lipid levels observed in winter dam samples may be associated not only with incomplete physiological development but also with seasonal factors, such as earlier harvest timing and reduced metabolic activity in colder water, as low temperatures are known to suppress lipid metabolism and accumulation in fish tissues.

According to the obtained findings, statistically significant differences were observed in terms of crude ash content, both among the groups and across the seasons ($p < 0.05$). In recent proximate composition analyses of slaughter-sized farmed *Salmo salar*, the ash content of Atlantic salmon fillets was reported to average approximately 1.6–2.2% on a wet weight basis, which aligns with previously published ranges for ash in salmon muscle tissue (Aas *et al*., 2022). Similarly, Erdem *et al*. (2020) reported an ash content of 1.13% in Atlantic salmon, while Keskin *et al*. (2022) found ash values of 1.03% in Turkish salmon and 0.79% in Atlantic salmon cultured in the Central Black Sea Region. When evaluated in the context of the existing literature, the crude ash values obtained in the present study fall within the previously reported ranges, suggesting a general consistency in mineral composition among salmonid species. Nevertheless, slight variations in ash content may arise from differences in environmental conditions, feeding practices, water mineral composition, and the physiological status of the fish. These findings highlight that, although ash content tends to remain within a relatively narrow range, it can still be influenced by both intrinsic and extrinsic factors associated with aquaculture systems.

Moisture content was highest in winter reservoir samples ($p < 0.05$), likely due to earlier harvesting and smaller fish size. In addition, the findings suggest a clear inverse relationship between moisture and crude fat content, a phenomenon commonly reported in fish muscle composition due to the replacement of water by lipid deposition during growth and maturation. An inverse relationship between moisture and lipid content was observed, consistent with prior studies in trout (Doan *et al*., 2020; Korkmaz and Öztürk, 2025). Overall, moisture values fall within typical ranges reported for rainbow trout, although minor variations may occur due to factors such as growth stage, environmental conditions, and culture practices.

Fatty acids profile of rainbow trout samples

The results of the fatty acid composition analysis of rainbow trout samples reared in marine and dam lake environments during the summer and winter seasons are summarized in Table 2.

Evaluation of the fatty acid profiles revealed clear seasonal and environmental variations in lipid composition. The total saturated fatty acid (SFA) content was higher in salmon harvested during the summer compared to the winter period, although palmitic acid (C16:0) remained the dominant SFA across all groups, with no statistically significant differences observed between seasons or rearing environments ($p > 0.05$). In contrast, the total monounsaturated fatty acid (MUFA) content was significantly lower in winter samples obtained from the dam ($p < 0.05$), with oleic acid (C18:1n-9) identified as the predominant MUFA. The elevated levels of these fatty acids are attributed to the inclusion of plant-based oils in aquafeeds, which directly influence fatty acid composition and promote their deposition in fish tissues (Turchini *et al*., 2009). The total polyunsaturated fatty acid (PUFA) content exhibited an opposite trend, with higher levels observed in both sea- and dam-reared salmon during the winter season, while comparatively lower values were recorded in summer samples. Linoleic acid (C18:2n-6) constituted a substantial proportion of the PUFA fraction. Moreover, total omega-3 fatty acids, particularly docosahexaenoic acid (DHA), were significantly elevated in dam-reared salmon compared to the other groups. The significantly elevated DHA levels in dam-reared salmon could be linked to differences in dietary omega-3 availability and

Table 2. Seasonal fatty acid analysis results of marine and dam lake salmon.

Fatty acid composition analysis (%)				
	Winter		Summer	
	Marine	Dam lake	Marine	Dam lake
C12:0	0,03 ± 0,00	0,03 ± 0.01	0.04 ± 0.00	0.04 ± 0.00
C13:0	0.01 ± 0.00	ND	ND	0.02 ± 0.01
C14:0	1.96 ± 0.05^{Aa}	1.62 ± 0.01^{Ab}	1.77 ± 0.03^{Aa}	1.93 ± 0.02^{Aa}
C15:0	0.17 ± 0.00	0.19 ± 0.00	0.03 ± 0.03	0.19 ± 0.01
C16:0	9.71 ± 2.60^{Bb}	11.81 ± 0.11^{Ab}	11.94 ± 0.10^{Ba}	13.11 ± 0.15^{Aa}
C17:0	0.21 ± 0.04	0.17 ± 0.01	0.20 ± 0.04	0.33 ± 0.01
C18:0	2.65 ± 0.79^{Bb}	3.57 ± 0.03^{Aa}	3.53 ± 0.08^{Aa}	4.15 ± 0.04^{Aa}
C20:0	0.40 ± 0.05	0.41 ± 0.01	0.42 ± 0.01	0.42 ± 0.01
C21:0	0.19 ± 0.01	0.12 ± 0.00	0.12 ± 0.00	0.14 ± 0.00
C22:0	0.52 ± 0.01	0.46 ± 0.01	0.51 ± 0.01	0.58 ± 0.01
C24:0	0.52 ± 0.05	0.31 ± 0.01	0.49 ± 0.04	0.52 ± 0.01
∑SFA	**16.40 ± 3.33^{Bb}**	**18.82 ± 0.13^{Ab}**	**19.34 ± 0.15^{Ba}**	**21.56 ± 0.15^{Aa}**
C14:1	0.03 ± 0.00	0.03 ± 0.00	0.06 ± 0.01	0.05 ± 0.01
C16:1	2.90 ± 0.14^{Aa}	2.34 ± 0.05^{Ab}	3.07 ± 0.15^{Aa}	3.25 ± 0.12^{Aa}
C15:1	ND	ND	0.02 ± 0.02	0.04 ± 0.01
C17:1	0.33 ± 0.02	0.24 ± 0.07	0.32 ± 0.03	0.33 ± 0.01
C18:1n9t	0.10 ± 0.01	0.10 ± 0.00	0.30 ± 0.41	0.06 ± 0.01
C18:1n9	36.05 ± 1.85^{Aa}	33.71 ± 0.18^{Ab}	36.49 ± 2.23^{Aa}	35.83 ± 0.42^{Aa}
C20:1n9	4.06 ± 0.14^{Aa}	3.17 ± 0.04^{Ba}	3.80 ± 0.10^{Aa}	3.42 ± 0.02^{Aa}
C22:1n9	0.70 ± 0.22^{Ab}	0.97 ± 0.02^{Aa}	0.78 ± 0.18^{Ab}	0.87 ± 0.01^{Aa}
∑MUFA	**44.17 ± 2.35^{Aa}**	**40.57 ± 0.21^{Bb}**	**44.85 ± 2.22^{Aa}**	**43.85 ± 0.53^{Aa}**
C18:2n6t	3.29 ± 0.09^{Aa}	3.35 ± 0.03^{Aa}	2.12 ± 1.84^{Ab}	2.83 ± 0.19^{Aa}
C18:2n6	15.98 ± 0.68^{Aa}	15.45 ± 0.33^{Aa}	14.05 ± 0.23^{Ab}	13.79 ± 0.09^{Ab}
C18:3n6	0.13 ± 0.01	0.11 ± 0.00	0.14 ± 0.00	0.14 ± 0.00
C18:3n3	3.90 ± 0.19^{Aa}	3.17 ± 0.04^{Aa}	3.45 ± 0.06^{Aa}	3.04 ± 0.02^{Aa}
C20:2	1.41 ± 0.08^{Aa}	1.11 ± 0.01^{Aa}	1.18 ± 0.02^{Aa}	1.20 ± 0.00^{Aa}
C20:3n3	1.49 ± 0.42^{Aa}	0.87 ± 0.03^{Ba}	0.81 ± 0.32^{Ab}	0.82 ± 0.03^{Aa}
C20:4n6	0.71 ± 0.02^{Aa}	0.52 ± 0.02^{Aa}	0.66 ± 0.02^{Aa}	0.51 ± 0.03^{Aa}
C20:5n3	1.99 ± 0.03^{Aa}	2.30 ± 0.08^{Aa}	1.99 ± 0.04^{Aa}	2.13 ± 0.01^{Aa}
C22:6n3	6.44 ± 0.15^{Ba}	10.64 ± 0.49^{Aa}	7.15 ± 0.36^{Aa}	6.09 ± 0.21^{Bb}
∑PUFA	**35.34 ± 1.04^{Aa}**	**37.52 ± 0.31^{Aa}**	**31.56 ± 2.21^{Ab}**	**30.55 ± 0.28^{Ab}**
∑n3	**13.81 ± 0.38^{Ba}**	**16.98 ± 0.63^{Aa}**	**13.405 ± 0.61^{Aa}**	**12.08 ± 0.21^{Ab}**
∑n6	**20.11 ± 0.62^{Aa}**	**19.43 ± 0.35^{Aa}**	**16.98 ± 1.77^{Ab}**	**17.27 ± 0.1^{Ab}**
∑n9	**40.90 ± 2.18^{Aa}**	**37.96 ± 0.12^{Bb}**	**41.38 ± 2.15^{Aa}**	**40.19 ± 0.42^{Ba}**
EPA/DHA	**0.31 ± 0.07^{Aa}**	**0.22 ± 0.01^{Ba}**	**0.28 ± 0.02^{Ba}**	**0.35 ± 0.04^{Aa}**
EPA+DHA	**8.42 ± 0.28^{Ba}**	**12.94 ± 0.73^{Aa}**	**9.13 ± 0.22^{Ab}**	**8.22 ± 0.35^{Ba}**

*MUFA (Monounsaturated fatty acids). PUFA (Polyunsaturated fatty acids). EPA (Eicosapentaenoic acid). DHA (Docosahexaenoic acid). n–3 (Omega-3 fatty acids). n–6 (Omega-6 fatty acids). n–9 (Omega-9 fatty acids), ND: Not Determined. Data are presented as mean ± standard deviation (n = 3). Superscript letters indicate statistically significant differences at $P < 0.05$: uppercase letters (A, B) denote differences between seasons within the same rearing environment, while lowercase letters (a, b) denote differences between rearing environments within the same season.

metabolic utilization, as dietary long-chain omega-3 fatty acids, such as DHA, are strongly associated with feed composition and are selectively deposited in fish muscle tissue when feeds are rich in these fatty acids, resulting in higher tissue DHA accretion in certain rearing environments (Wu *et al*., 2024).

Previous studies have reported comparable PUFA and omega-3 fatty acid profiles in salmonid species. Keskin *et al*. (2022) reported total PUFA contents of 36.54% in Turkish salmon and 37.08% in Atlantic salmon, with EPA + DHA levels of 7.54% and 7.88%, respectively ($p < 0.05$). Similarly, Kaya Öztürk *et al*. (2019) and Pekcan (2016) documented substantial levels of total PUFA and omega-3 fatty acids in Turkish salmon, while Erdem *et al*. (2020) reported total PUFA and n-3 values of 45.03% and 14.56% in trout, and 36.68% and 18.17% in Atlantic salmon, respectively. These findings collectively confirm that Turkish salmon is characterized by a high content of omega-3 fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Environmental factors such as oxygen availability and salinity are known to influence lipid metabolism and fatty acid deposition, with freshwater and hypoxic conditions often promoting the accumulation of unsaturated fatty acids (Sampels, 2015).

In line with the literature, linoleic and α-linolenic acids were detected at notable levels in all rainbow trout samples analyzed in this study, while EPA and DHA contents were also found to be relatively high. Given that fish oil is a major source of long-chain polyunsaturated fatty acids (Sahena *et al*., 2009), these results highlight the nutritional importance of the studied samples. Recent nutritional research emphasizes the importance of a balanced dietary intake of omega-6 and omega-3 polyunsaturated fatty acids, with a lower omega-6/omega-3 ratio—ideally between approximately 1:1 and 4:1—being associated with reduced pro-inflammatory responses and improved metabolic health outcomes, in contrast to higher ratios typical of Western diets (Gutierres *et al*., 2025). The n-6/n-3 ratio of unsaturated fatty acids is associated with the causes of mortality from cancer and cardiovascular diseases (Hoz *et al*., 2004). This ratio has also been reported to be an important indicator used to compare the nutritional value of fish oil (Durmuş and Kara, 2024). According to the omega-6/omega-3 ratio results obtained in the study, Turkish salmon samples exhibit favorable ratios. Recent studies report that EPA + DHA content typically ranges between 15% and 30% of total fatty acids in farmed rainbow trout (Gladyshev *et al*., 2022). In agreement with these results, Sprague *et al*. (2020) analyzed farmed Atlantic salmon fillets from UK retailers, reporting EPA + DHA contents ranging from 5.6% to 16.6% of total fatty acids, with some samples delivering ≥1 g EPA + DHA per 100 g fillet.

Content of amino acids profile in Turkish salmon

In the present study, the amino acid composition of rainbow trout samples cultured in marine and dam lake environments during the summer and winter seasons is presented in Table 3.

The total amino acid content did not differ significantly among seasons or rearing environments, indicating a relatively stable amino acid profile in rainbow trout. Among the detected amino acids, anserine was consistently the most abundant across all groups. This predominance may be attributed to its critical physiological roles in muscle tissue, including antioxidant activity, intracellular pH buffering, and protection against reactive oxygen species (Boldyrev *et al*., 2013). Glycine was identified as the second most abundant amino acid, with the highest levels observed in dam-reared trout harvested during winter. This increase may be associated with environmental stress and reduced growth rates under colder conditions, given glycine's involvement in connective tissue synthesis and its function as a precursor for glutathione in oxidative stress defense (Wu, 2009).

Among essential amino acids, leucine, valine, and threonine were present at relatively high levels, while taurine was also detected in considerable amounts across all groups. Taurine, a sulfur-containing, conditionally essential amino acid, is known to contribute to osmoregulation, membrane stabilization, and antioxidant protection. Previous studies have reported comparable amino acid profiles in salmonids, although quantitative variations are evident. For instance, Colombo and Mazal (2020) reported total amino acid contents of 18.8 g/100 g and 17.9 g/100 g for farmed and organic Atlantic salmon, respectively, while Çankırılıgil and Berik (2017) determined a total amino acid content of 16.5 g/100 g in trout, with aspartic acid, lysine, leucine, and glutamic acid being predominant. In comparison, the relatively lower amino acid values observed in the present study may be attributed to differences in feeding regime, fish size and age, environmental conditions (e.g., water temperature and quality), and protein metabolism dynamics.

It is well established that amino acid composition in fish is influenced by multiple intrinsic and extrinsic factors, including species-specific characteristics, seasonal variation, feeding strategies, and reproductive cycles (Çankırılıgil, 2019; Pigott and Tucker, 1990). Additionally, regional and environmental conditions, such as water quality and harvesting period, have been reported to affect both the quantity and composition of amino acids (Wesselinova, 2000). Therefore, the variations observed in this study are likely the result of the combined effects of aquaculture practices, environmental conditions, and seasonal dynamics.

Table 3. Seasonal amino acid analysis results of marine and dam lake salmon.

Amino acid analyses (g/100 g)				
	Winter		Summer	
	Marine	Dam lake	Marine	Dam lake
EAA*				
Tryptophan	0.01 ± 0.00	ND	ND	0.01 ± 0.00
Phenylalanine	0.04 ± 0.00	0.02 ± 0.00	0.03 ± 0.00	0.04 ± 0.00
Leucine	0.22 ± 0.03^{Aa}	0.12 ± 0.00^{Ba}	0.14 ± 0.01^{Aa}	0.18 ± 0.02^{Aa}
Isoleucine	0.09 ± 0.01	0.08 ± 0.00	0.08 ± 0.01	0.09 ± 0.01
Methionine	0.10 ± 0.01	0.03 ± 0.00	0.03 ± 0.00	0.06 ± 0.00
Valine	0.15 ± 0.02^{Aa}	0.12 ± 0.00^{Aa}	0.14 ± 0.00^{Aa}	0.13 ± 0.01^{Aa}
Threonine	0.13 ± 0.00^{Ab}	0.18 ± 0.02^{Aa}	0.16 ± 0.01^{Aa}	0.19 ± 0.02^{Aa}
Histidine	0.44 ± 0.01^{Aa}	0.31 ± 0.01^{Aa}	0.20 ± 0.02^{Ba}	0.49 ± 0.02^{Aa}
Lysine	0.09 ± 0.02^{Aa}	0.10 ± 0.02^{Aa}	0.11 ± 0.02^{Aa}	0.06 ± 0.00^{Bb}
NEAA*				
Tyrosine	0.17 ± 0.02^{Aa}	0.07 ± 0.00^{Ba}	0.10 ± 0.00^{Aa}	0.15 ± 0.01^{Aa}
Glutamic acid	0.19 ± 0.01^{Ba}	0.31 ± 0.03^{Aa}	0.28 ± 0.02^{Aa}	0.19 ± 0.01^{Ba}
Aspartic acid	0.08 ± 0.01	0.07 ± 0.00	0.04 ± 0.00	0.03 ± 0.00
Serine	0.13 ± 0.01^{Ba}	0.25 ± 0.02^{Aa}	0.14 ± 0.02^{Ab}	0.15 ± 0.00^{Aa}
Alanine	0.36 ± 0.02^{Ba}	0.68 ± 0.05^{Aa}	0.48 ± 0.03^{Ab}	0.35 ± 0.01^{Ba}
Glycine	1.18 ± 0.12^{Ba}	2.08 ± 0.02^{Aa}	1.58 ± 0.02^{Ab}	1.03 ± 0.04^{Ba}
Asparagine	0.02 ± 0.00^{Ab}	0.01 ± 0.00^{Aa}	0.02 ± 0.00^{Ba}	0.13 ± 0.02^{Aa}
Anserine	7.11 ± 0.08^{Aa}	5.20 ± 0.81^{Bb}	6.75 ± 0.12^{Aa}	7.03 ± 0.23^{Aa}
Proline	0.07 ± 0.01^{Ab}	0.09 ± 0.02^{Aa}	0.07 ± 0.00^{Ba}	0.19 ± 0.03^{Aa}
Glutamine	0.03 ± 0.00	0.03 ± 0.00	0.05 ± 0.00	0.09 ± 0.02
Cysteine	ND	ND	ND	ND
Arginine	0.06 ± 0.00	0.07 ± 0.01	0.07 ± 0.00	0.05 ± 0.00
Taurine	0.62 ± 0.01^{Ab}	0.81 ± 0.02^{Aa}	0.93 ± 0.02^{Aa}	1.02 ± 0.06^{Aa}
∑AA*	**11.65 ± 0.80^{Aa}**	**10.99 ± 0.42^{Aa}**	**11.63 ± 0.82^{Aa}**	**11.96 ± 1.01^{Aa}**

*EAA: Essential amino acid. NEAA: Non-Essential Amino acid. ∑AA: Total Amino acid. ND: Not Determined. Data are presented as mean ± standard deviation (n = 3). Superscript letters indicate statistically significant differences at $P < 0.05$: uppercase letters (A, B) denote differences between seasons within the same rearing environment, while lowercase letters (a, b) denote differences between rearing environments within the same season.

Mineral matter of trout samples

The results of the mineral composition analysis of rainbow trout samples reared in marine and dam lake environments during the summer and winter seasons are summarized in Table 4.

The mineral composition analysis revealed that potassium (K) and phosphorus (P) were the predominant elements across all experimental groups. Notably, K levels were higher in samples obtained from Kürtün Dam Lake, whereas iron (Fe) was detected only in the dam lake samples during the summer season (0.14 mg/kg). In contrast, calcium (Ca) levels were comparatively lower in the Kürtün Dam Lake group, while zinc (Zn) concentrations reached their highest values in the winter samples from the same environment. Despite these variations, no statistically significant differences were observed among groups in relation to season or rearing conditions ($p > 0.05$).

Minerals are essential dietary components that play a critical role in maintaining physiological functions and enhancing nutritional quality, as they cannot be synthesized by the human body and must be obtained through food intake. Seafood, in particular, is recognized as a rich source of essential minerals. However, when compared with previously reported values for farmed Atlantic salmon (Atanasoff *et al*., 2013), the mineral concentrations obtained in the present study were generally

Table 4. Seasonal mineral substance analysis results of marine and dam lake salmon.

Mineral substance (mg/kg)				
	Winter		Summer	
	Marine	Dam lake	Marine	Dam lake
Sodium (Na)	183.23 ± 1.62^{Aa}	188.98 ± 1.10^{Aa}	171.59 ± 1.23^{Aa}	191.89 ± 2.02^{Aa}
Magnesium (Mg)	119.12 ± 1.42^{Aa}	107.02 ± 2.14^{Ba}	111.56 ± 0.97^{Aa}	116.62 ± 1.78^{Aa}
Phosphorus (P)	1085.57 ± 2.91^{Aa}	1098.05 ± 1.89^{Aa}	972.16 ± 2.86^{Bb}	1071.07 ± 3.82^{Aa}
Potassium (K)	1411.64 ± 4.71^{Aa}	1238.10 ± 2.36^{Ba}	1296.65 ± 3.20^{Aa}	1308.76 ± 2.94^{Ab}
Calcium (Ca)	3.28 ± 0.29^{Ba}	4.76 ± 0.68^{Aa}	4.70 ± 0.83^{Aa}	4.30 ± 0.52^{Aa}
Iron (Fe)	ND	ND	ND	0.14 ± 0.02^{Aa}
Zinc (Zn)	1.31 ± 0.02^{Ba}	2.46 ± 0.16^{Aa}	1.20 ± 0.08^{Ab}	1.36 ± 0.01^{Aa}

ND: Not Determined. Data are presented as mean ± standard deviation (n = 3). Superscript letters indicate statistically significant differences at $P < 0.05$: uppercase letters (A, B) denote differences between seasons within the same rearing environment, while lowercase letters (a, b) denote differences between rearing environments within the same season.

lower. These discrepancies may be attributed to multiple factors, including differences in fish size, lipid content, environmental conditions, seasonal variation, and feeding regimes. Collectively, these factors are known to influence mineral accumulation and distribution in fish tissues, thereby contributing to variability in mineral composition across studies.

Vitamin analysis results of trout samples

The composition of fat- and water-soluble vitamins in rainbow trout (*Oncorhynchus mykiss*) samples cultured in marine and dam lake environments during the summer and winter seasons is presented in Table 5.

In this study, among the fat-soluble vitamins, only vitamins E and D3 were detected, while vitamins A and K were below detectable levels. The highest concentrations of vitamins E and D3 were observed in samples from the dam environment. Vitamin E serves as a lipid-soluble antioxidant, and its increased presence in dam fish could be associated with differences in lipid metabolism or feed composition, as vitamin E is often supplemented in aquafeeds to prevent oxidative degradation of fats (El-Sayed and Izquierdo, 2022). Regarding water-soluble vitamins, niacinamide, pantothenic acid, and nicotinic acid were present in the greatest amounts across the sample groups. Elevated levels of vitamins B1 and B11 were noted during the summer period. Vitamin B2 concentrations were higher in dam-reared fish, while vitamin B3 levels peaked in dam-harvested salmon during the winter season. Additionally, niacinamide and vitamin B5 were found at increased levels in dam samples collected in summer. Vitamin C was not detected in any of the samples.

Dias *et al*. (2003) determined the amounts of vitamins A, D, and E in the fillet of Atlantic salmon as 33 μg/100 g, 11 μg/100 g, and 4 mg/100 g, respectively, and in the fillet of rainbow trout as 8.8 μg/100 g, 19.0 μg/100 g, and 0.13 mg/100 g, respectively. Vutov *et al*. (2015) reported the amounts of vitamins A, D3, and E in rainbow trout fillet as 22.3 μg/100 g, 6 μg/100 g, and 809.1 μg/100 g, respectively. In a comparative analysis of fat-soluble vitamins in the edible tissue of farmed trout species, rainbow trout (*Oncorhynchus mykiss*) muscle was reported to contain measurable retinol (vitamin A) and α-tocopherol (vitamin E) concentrations in fresh fillet, supporting the significant contribution of these vitamins to the nutritional quality of farmed trout flesh (Stancheva and Dobreva, 2013). Küçük (2019) analyzed vitamin E in samples of rainbow trout from Türkiye and determined average values of 36.22 mg/kg based on alpha-tocopherol. Reksten *et al*. (2022) analyzed nutritional values in 1108 Norwegian farmed Atlantic salmon samples collected between 2005 and 2020. The vitamin D3 content remained relatively stable over the years, with average values ranging from 6.0 to 9.2 μg/100 g. Başaran (2015), in a study on vitamin and mineral loss in rainbow trout due to different processing techniques, reported the vitamin content of raw fish as follows: B1: 6.26 μg/g, B2: 2.86 μg/g, B3: 8.88 μg/g, B6: 2.60 μg/g, A: 8.66 μg/g, and C: 21.80 μg/g. Ural *et al*. (2025) determined antioxidant vitamin levels, including vitamin C, in the flesh of pond-, cage-, and wild-reared rainbow trout and reported vitamin C concentrations of 57.85–65.54 μg/g across sample groups. Vitamin stability is highly sensitive to sample handling, storage conditions, and analytical limitations, particularly for vitamins such as A and C, which are prone to degradation (Elbahnaswy and Elshopakey, 2024). The concentrations of B-group vitamins observed in this study were lower compared to those reported in the existing literature. The absence of vitamin C in all samples is likely

Table 5. Seasonal vitamin analysis results of marine and dam lake salmon.

Vitamin analysis				
	Winter		Summer	
Fat soluble vitamins (mg /100 g)	**Marine**	**Dam lake**	**Marine**	**Dam lake**
Vitamin D_3	0.31 ± 0.04^{Ab}	0.43 ± 0.03^{Aa}	0.21 ± 0.01^{Bb}	0.43 ± 0.06^{Aa}
Vitamin E	1.00 ± 0.08^{Bb}	1.51 ± 0.17^{Aa}	1.36 ± 0.12^{Bb}	1.60 ± 0.20^{Aa}
Water soluble vitamins (µg/g)				
Thiamine (B_1)	0.01 ± 0.00^{Bb}	0.05 ± 0.00^{Ab}	0.13 ± 0.01^{Ba}	0.26 ± 0.03^{Ba}
Riboflavin (B_2)	0.07 ± 0.00^{Bb}	0.11 ± 0.01^{Aa}	0.08 ± 0.00^{Bb}	0.12 ± 0.01^{Aa}
Nicotinic Acid (B_3)	0.30 ± 0.02^{Ba}	0.94 ± 0.11^{Aa}	0.41 ± 0.01^{Ab}	0.21 ± 0.00^{Ba}
Niacinamide (B_3)	2.83 ± 0.22^{Ab}	2.67 ± 0.14^{Aa}	2.99 ± 0.38^{Ba}	6.36 ± 0.74^{Aa}
Pantothenic Acid (B_5)	0.32 ± 0.02^{Bb}	0.70 ± 0.03^{Aa}	0.86 ± 0.05^{Ba}	2.80 ± 0.42^{Aa}
Folic Acid (B_{11})	0.02 ± 0.00^{Ab}	0.06 ± 0.00^{Ab}	0.11 ± 0.00^{Aa}	0.15 ± 0.02^{Aa}

Data are presented as mean ± standard deviation (n = 3). Superscript letters indicate statistically significant differences at $P < 0.05$: uppercase letters (A, B) denote differences between seasons within the same rearing environment, while lowercase letters (a, b) denote differences between rearing environments within the same season.

not a biological characteristic but rather due to its high instability, as vitamin C is highly sensitive to oxidation, heat, light exposure, and processing conditions, which can lead to significant degradation during sample processing and storage. It is likely to degrade when exposed to high temperatures in prepared feed formulations.

Conclusions

This study demonstrates that seasonal and environmental conditions significantly affect the nutritional composition of Turkish salmon (*Oncorhynchus mykiss*). By highlighting seasonal and regional variations in nutrient profiles, the findings provide valuable insights for optimizing harvest timing and production strategies. While protein and amino acid profiles remained stable, lipid content showed pronounced variation, with higher levels in sea-reared fish during winter and in dam-reared fish during summer, alongside a clear inverse relationship with moisture. The species was confirmed as a valuable source of omega-3 fatty acids (notably DHA and EPA), with elevated DHA levels in dam-reared samples. Mineral composition remained relatively consistent, whereas vitamin analysis indicated the predominance of vitamins E and D3 and the absence of vitamin C, likely due to its instability. Importantly, from a practical and actionable perspective, sea-reared salmon harvested in winter appears preferable for higher fat and omega-3 content, whereas dam-reared salmon harvested in summer is more favorable in terms of protein content, highlighting the applied value of these findings for the aquaculture sector. These results underscore the strong influence of production system and season on fish quality and provide meaningful guidance for both industry and consumers. Future research should focus on disentangling the effects of feed composition and environmental factors, as well as improving vitamin retention through optimized handling and processing strategies. Overall, this research offers a meaningful contribution to both scientific knowledge and practical applications within the food and aquaculture sectors.

Mandatory Disclosure on Use of Artificial Intelligence

The authors declare that AI-assisted tools were used as follows: ChatGPT (OpenAI) for grammar checking and rephrasing of the manuscript text. All references have been manually verified for accuracy and relevance.

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Author Contributions

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Resources: N.T.; Supervision: Y.A.; Validation: N.T. and Y.A.; Writing – original draft: N.T. and Y.A.; Writing – review and editing: N.T. and Y.A.

Conflicts of Interest

The authors declare no conflict of interest.

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Supplementary

TABLE S1 Liquid Chromatograph-Mass Spectrophotometer (LC-MS-MS) parameters related to amino acid

Parameters for LC	Conditions
Mobile phase A	30 mM Amonyum Format + %3 Formik Asit + UPW
Mobile phase B	ACN
Colon	Zorbax-hilic
Colon temperature	25°C
Injection Volume	5 µL
Parameters for MS-MS	
Ion Source	Electrospray Ionization (ESI)
Ionization Type	Positive
Capillary Voltage	3000 V
Source Temperature	375 °C
Nitrogen Gas Temperature	300 °C
Nitrogen Gas Flow	10 L/min
Delta EMV (+)	0 V

TABLE S2 LC device parameters related to water-fat-soluble vitamins

Parameters	Conditions for WSV*	Conditions for FSV*
Mobil Phase A	5 mM Ammonium Formate + 0.1% Formic Acid + Ultrapure Water	0.1% Formic Acid + Ultrapure Water
Mobil Phase B	Methanol with 0.1% Formic acid	Methanol with 0.1% Formic acid
Colon Temperature	25°C	25°C
Sampler Temperature	4°C	4°C
Colon	Zorbax-Extend-C18	Phenomenex
Injection volume	5 µL	5 µL

*water soluble vitamins (WSV), fat soluble vitamins (FSV)