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Utilization of Fish By-Products for Sustainable Aquaculture: Nutritional Analysis of Fishmeal derived from the By-Products of *Oncorhynchus mykiss*

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Abstract

This study aims to investigate the nutritional composition of fishmeal derived from the by-products of Oncorhynchus mykiss, commonly known as Turkish Salmon, cultured in the Black Sea. The findings indicate that the obtained fishmeal possesses high crude protein content (65.22 ± 0.118%) and crude fat content (9.28 ± 0.139%). Additionally, the energy value of the fishmeal was determined to be 358.75 ± 3.633 kcal/g. Mineral substance analysis reveals significant levels of calcium, phosphorus, and magnesium in the fishmeal. Heavy metal analysis results indicate arsenic, lead, cadmium, and mercury contents of 3.51 ± 0.470, 1.46 ± 0.136, 0.15 ± 0.004, and 0.007 ± 0.012 mg/kg, respectively. These findings suggest that fishmeal derived from processing residues of Turkish Salmon offers high nutritional value and could be considered as an alternative raw material for sustainable aquaculture. This study is expected to contribute significantly to waste management and sustainability efforts in the fish processing industry.

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INTRODUCTION

As the world's population continues to grow, there is an anticipation of increased demand for seafood, but changing climatic conditions are expected to reduce fishing yields (Tacon, 2002). In this context, the aquaculture sector plays a critical role in ensuring the nutrition of the global population. According to data from the Food and Agriculture Organization (FAO, 2019), the aquaculture sector has become the fastest-growing food production sector worldwide, with an average annual growth rate of 6.6% in the last decade (Bayrakli et al., 2019; Bayrakli & Duyar, 2021b; Duyar & Bayrakli, 2023). Currently, half of the global seafood production is sourced from aquaculture, and it is expected that aquaculture will surpass wild-caught fisheries in the near future (FAO, 2019).

In Turkey, the aquaculture sector has also been rapidly expanding, reaching 515,000 tons in 2021, which is 1.54 times the quantity obtained from wild-caught fisheries (TÜİK, 2023). This growth has led to an increasing demand for fishmeal and fish oil, with inevitable price hikes due to production limitations (Bayrakli & Duyar, 2019a, 2019b; Kristofersson & Anderson, 2004). Consequently, the costs associated with farmed fish are closely tied to the prices of fishmeal (Bayrakli et al., 2019; Bayrakli & Duyar, 2005; Duyar & Bayrakli, 2023). Despite their high costs, fishmeal and fish oil are indispensable for fish nutrition, and suitable alternatives are limited (Bayrakli & Duyar, 2021a; Einarsson et al., 2019).

In Turkey, the fishmeal market cannot meet domestic demand due to insufficient raw material supply (Bayrakli & Duyar, 2021a). Therefore, the factories supplying feed to the aquaculture sector in our country need to import a significant portion of the required fishmeal. However, considering the growth trend in the aquaculture sector, an increase in fishmeal imports is anticipated. Thus, for the country's economy, it is crucial for Turkey to explore alternative raw materials in the fishmeal sector and adopt sustainable policies (Bayrakli & Duyar, 2021b).

While fishmeal production based on fishery catches is limited worldwide, the potential for using fish by-products and waste is significant as aquaculture production increases. According to TUIK (2023) data, while the Black Sea Salmon produced on land and in the sea in Turkey was 123 089 tons in 2019, this production reached 191 500 tons in 2022. This upward trend in production, particularly in sea-based operations, leads to a proportional increase in by-products. These by-products encompass fish parts removed before reaching consumers to maintain fish quality, reduce transportation costs, or enhance the value of the main fish product. They contain substantial amounts of fat and protein, making them valuable resources for human consumption and animal feed, from a nutritional and food safety perspective (Ramirez, 2007). The primary components of aquaculture discards include the head, internal organs, gills, bones, scales, fins, and sometimes skin. Depending on fish processing techniques and species, a substantial amount of waste (20-80%) is generated (Ghaly et al., 2013).

In 2019, the Republic of Turkey's Ministry of Agriculture and Forestry, specifically the General Directorate of Fisheries and Aquaculture, responded to a request from aquaculture producers and officially designated the Rainbow Trout as "Turkish Salmon" (Özal, 2021). Salmon farming and processing facilities located in the Black Sea region have become pivotal in meeting the increasing demand for these fish. Nevertheless, this expansion has resulted in the generation of diverse fish by-products within fish processing plants. Effectively harnessing the potential of these by-products is not only essential for ensuring the sustainability of the industry but also for the responsible conservation of natural resources.

Traditionally, such fish by-products are often considered waste and can contribute to environmental problems. However, recognizing the potential value of these by-products can be a significant step toward sustainability. Therefore, this study focuses on evaluating fish by-products produced by a fish processing facility in the Black Sea region. The main objective of the study is to investigate the process of obtaining fishmeal from these fish by-products and analyze the nutritional composition of this fishmeal. Specifically, the data obtained are examined to assess whether this fishmeal could serve as a potential alternative raw material for sustainable aquaculture.

The results of this study can provide crucial information to support waste management and sustainability efforts in the fish processing industry in the Black Sea region. Additionally, it may serve as an inspiration to other similar industries on how waste products can be effectively utilized to reduce environmental impacts and make more efficient use of natural resources. This article delves into the nutrient composition and elemental content of fishmeal derived from the by-products of farmed Black Sea Salmon (Oncorhynchus mykiss). By understanding the nutritional profile of fishmeal, we can identify potential alternative ingredients and develop sustainable aquaculture practices.

MATERIALS and METHODS

Samples were obtained from a fishmeal and oil factory located in Samsun in May 2022. Three sacks were opened from the factory's storage area, and samples of fishmeal derived from Salmon Processing By-Products (SBP-FM) were collected using a scoop and mixed in a plastic container. Three 1 kg samples were taken from the mixture, placed in nylon bags, and labeled.

For laboratory analysis, the samples were sent to Sinop University Scientific and Technological Research Application and Research Center. This center is equipped with a laboratory infrastructure that ensures reliable analysis procedures in compliance with standardized protocols.

Nutrient Composition Analysis

Nutrient composition analyses (moisture, crude protein, crude fat, and crude ash) were performed according to the standard AOAC method (AOAC 1990). Total carbohydrate content was calculated by subtracting the sum of crude protein, crude fat, moisture, and crude ash from 100 (Ferris et al., 1995; Anonymous, 2005). The energy content was expressed as kilocalories per gram (kcal/g) in fishmeal samples and was calculated from the percentages of crude protein, total carbohydrate, and crude fat. Conversion factors used were 4.0 kcal/g for protein and carbohydrates and 9.0 kcal/g for total fat (Ferris et al., 1995; Merrill and Watt, 1973). Total Energy = (Crude Protein * 4) + (Carbohydrate * 4) + (Crude Fat * 9).

Table 1: Nutrient Composition of SBP-FM

	SBP-FM		
Crude Protein (%)	65.22	±	0.118
Crude Fat (%)	9.28	±	0.139
Ash (%)	9.89	±	0.786
Moisture (%)	12.02	±	0.170
Carbohydrates (%)	3.58	±	1.102
Energy Content (kcal/g)	358.75	±	3.633

Elemental Analysis

For mineral substance analysis, homogenized fishmeal samples were weighed (1 g) in high-pressure-resistant Teflon containers (10 ml volume, 200 psi pressure-resistant). Then, 4 ml of nitric acid (65%) (Merck, 1.00452) was added to each container. Wet combustion was applied to the Teflon containers in a closed-system microwave oven. The temperature gradually reached 150°C within the first 15 minutes and was maintained at this temperature for 5 minutes. After the pressure dropped below 50 psi, the temperature was allowed to reach 250°C within 15 minutes, and it was maintained at this temperature for 5 minutes. After cooling at the end of wet combustion, the burned samples were washed with ultrapure water, transferred into 14 ml Falcon tubes, and filled with ultrapure water. Then, readings were taken using the Perkin Elmer ICP-OES Optima 2100 DV spectrometer following the EPA (1994) guidelines.

RESULTS and DISCUSSION

Fishmeal derived from the by-products of farmed Black Sea Salmon exhibited a high crude protein content, approximately 65.219 ± 0.118%. This finding underscores fishmeal's significance as a rich source of essential amino acids, which play a pivotal role in the growth and development of farmed fish. Furthermore, the crude fat content of the fishmeal measured at approximately 9.28 ± 0.139%, indicating that it serves as a valuable source of energy for fish. The moderate carbohydrate content, approximately 3.58 ± 1.103%, contributes to the overall nutritional profile of the feed.

An elemental content analysis of the fishmeal reveals the presence of several essential minerals and trace elements. The crude ash content, which represents the mineral content, is approximately 9.89 ± 0.786%. This suggests that fishmeal may serve as a valuable source of minerals such as calcium, phosphorus, and magnesium, which are essential for the overall health and development of fish.

In this study, the carbohydrate content was found to be %3.58 ± 1.102, and the energy value was determined as 358.75 ± 3.633 kcal/g. Bayrakli and Duyar (2021b) reported lower carbohydrate values for anchovy and sprat meal, namely %0.80 ± 0.085 and %0.96 ± 0.176, respectively, while the energy values were found to be similar to the results of this study, measuring at 366.47 ± 2.237 kcal/g and 367.11 ± 1.824 kcal/g, respectively. It is observed that SBP-FM is as rich in energy as fishmeal derived from anchovy and sprat. The high carbohydrate content of fishmeal offers greater potential for various applications, but harnessing this potential to its fullest extent may require careful balancing of feed formulations.

Fishmeal is considered one of the most important protein sources, especially in animal husbandry (Chen et al., 2023). The crude protein content of fishmeal varies in many studies. Zarkadas et al. (1986) reported a crude protein content of %65.8 in fish by-products, De Koning (2002) found values ranging from %61.56 to %68.26 in fishmeals derived from various sources such as anchovy, mackerel, and fish by-products. De Koning (2005), in another study involving different raw materials, reported crude protein contents of %60-70 in fishmeals. Moghaddam et al. (2007) reported a crude protein content of %59.1 ± 2.02 in kilka meal. They also stated that the crude protein content in the global fishmeal market was %64.2 for anchovy meal, %72.3 for herring meal, and %60.5 for menhaden meal. Duyar and Bayraklı (2005) reported that the crude protein content of samples obtained from factories in Sinop province, Turkey, ranged from %66.50 to %76.00 between 2000 and 2005. Bayrakli and Duyar (2019) reported crude protein contents of 72.56% and 66.68% for anchovy meal and sprat meal, respectively. Bayrakli and Duyar (2021a) indicated that crude protein values in anchovy meal ranged from 68.02% to 76.63% and that these values varied depending on the freshness of the raw materials and the processing factories. In this study, the values of SBP-FM were similar to those of other fishmeals except for anchovy meal. It can be said that the crude protein content in fishmeal varies depending on the type of raw material used.

In various fishmeals obtained from different raw materials, crude fat content was found to be %3.4 in fish by-products by Zarkadas (1986), %10.28-%14.49 in fishmeals from various sources by De Koning (2002), %10-15 in fishmeals from different raw materials in another study by De Koning (2005), %7.44 in herring meal by Kausoulaki et al. (2009), and %10.6 in sardine meal by Bassompierre et al. (1998). Moghaddam et al. (2007) reported a crude fat content of %22.9 ± 1.91 in kilka meal. They also stated that in the global fishmeal market, crude fat content was %5.0 for anchovy meal, %10 for mackerel meal, and %9.4 for menhaden meal. Duyar and Bayrakli (2005) reported that the crude fat content of samples obtained from factories in Sinop province, Turkey, ranged from %7.70 to %14.20. Bayrakli and Duyar (2019a) reported crude fat contents of 8.12% for anchovy meal and 10.73% for sprat meal. Bayrakli and Duyar (2021a) stated that crude fat values in anchovy meal ranged from 7.52% to 12.44%. The obtained crude fat values are in line with the values reported by other researchers.

To minimize bacterial growth in fishmeal, it is desired to have a moisture content of less than 10% (Bayrakli & Duyar, 2019a, 2019b). Kausoulaki et al. (2009) found a moisture content of %7.1 in herring meal, while De Koning (2005) found moisture content ranging from 5% to 10% in fishmeals obtained from various fish species. Moghaddam et al. (2007) reported a moisture content of %5.5 in kilka fishmeals produced in different factories in Iran. They also reported moisture contents of %8.0 in anchovy meal, %7.0 in mackerel meal, and %8.0 in menhaden meal in the global fishmeal market. Bayrakli and Duyar (2019a) reported moisture contents of 7.78% for anchovy meal and 6.41% for sprat meal. Bayrakli and Duyar (2021a) indicated that moisture values in anchovy meal ranged from 3.54% to 6.51%. In this study, although the moisture content of fishmeal obtained was among the reported values in other studies, it was higher than the values reported for anchovy meal.

The ash content in fishmeals obtained from various raw materials was reported to be %10-25 by De Koning (2005), %10.34 in herring meal by Kausoulaki et al. (2009), %13.2 ± 0.98 in kilka meal by Moghaddam et al. (2007), and %9.7 in sardine meal by Bassompierre et al. (1998). Zarkadas (1986) reported an ash content of 20% in fish by-products, while Cho et al. (1987) reported ash contents of %15.7 in herring meal and %26.4 in shrimp meal. Duyar and Bayrakli (2005) reported that the ash content of samples obtained from factories in Sinop province, Turkey, ranged from %7.70 to %14.20. Bayrakli and Duyar (2019a) reported ash contents of 10.75% for anchovy meal and 15.23% for sprat meal. Bayrakli and Duyar (2021a) stated that ash values in anchovy meal ranged from 10.73% to 11.73%. In this study, the obtained ash content was lower than the values reported for other types of fishmeal, similar to anchovy meal. It has been reported that the nutritional composition of fishmeal varies depending on the species of fish, whether it is made from the whole fish or fish by-products, and the processing method (Bayrakli & Duyar, 2021b). An elemental content analysis of SBP-FM is presented in Table 2. Macroelement concentrations were found to follow the order Ca > P > K > Na > Mg. Meanwhile, trace element concentrations were observed as follows: Fe > Al > Zn > Mn > Ti > Cu > Ba > B > Cr > Ni > Se > Rb > V > Li > Si > Co > Mo > Ga > Sr > Sn > U > Gd > Sb > Be > Cs. Heavy metal concentrations followed the sequence As > Pb > Cd > Hg.

Table 2. Element Concentrations in SBP-FM

Trace Elements (mg kg^{-1})				Macro Elements (g kg^{-1})				Heavy Metals (mg kg^{-1})			
Fe	4050.01	±	42.375	Ca	27.18	±	0.249	As	3.51	±	0.470
Al	698.13	±	16.118	P	23.28	±	0.055	Pb	1.46	±	0.136
Zn	179.94	±	2.029	K	5.04	±	0.086	Cd	0.15	±	0.004
Mn	56.08	±	1.415	Na	4.58	±	0.042	Hg	0.07	±	0.012
Ti	18.82	±	1.518	Mg	3.16	±	0.038				
Cu	11.67	±	0.025								
Ba	5.61	±	0.069								
B	4.87	±	0.087								
Cr	4.63	±	0.084								
Ni	4.46	±	0.077								
Se	2.28	±	0.739								
Rb	1.61	±	0.016								
V	1.54	±	0.023								
Li	1.14	±	0.013								
Si	0.86	±	0.007								
Co	0.58	±	0.004								
Mo	0.37	±	0.015								
Ga	0.32	±	0.064								
Sr	0.31	±	0.088								
Sn	0.14	±	0.008								
U	0.06	±	0.003								
Gd	0.05	±	0.004								
Sb	0.05	±	0.005								
Be	0.03	±	0.001								
Cs	0.03	±	0.005								

Table 3 displays the elemental contents of fishmeal obtained from various raw materials. Calcium (Ca) was found to be the most abundant element in fishmeal, with a concentration of 27.18 g kg-1, falling within the reported range of 3.93-52.20 g kg-1 in the literature. Phosphorus (P) content was determined as 23.28 g kg-1 in this study, with literature values ranging from 4.40 to 29.30 g kg-1. The potassium (K) content was relatively low at 5.04 g kg-1 in this research, which was consistent with previous literature, including Bayrakli and Duyar (2021b), focused on herring meal. Sodium (Na) content was found to be 4.58 g kg-1, lower than reported in most studies except for Irungu et al. (2018). Magnesium (Mg) and iron (Fe) values exceeded those reported in Table 3 by other research findings. Manganese (Mn) was determined at 56.08 mg kg-1, surpassing values reported by all studies except Irungu et al. (2018). Copper (Cu) content was in line with Satoh et al. (1987) but higher than other studies except Irungu et al. (2018). It's important to note that variations in fishmeal mineral composition can be attributed to seasonal and biological factors (such as species, muscle type, sex, sexual maturity, breeding conditions, water chemistry, salinity, temperature), processing methods, and the source of fish used (Bayrakli & Duyar, 2021b).

Table 3. Elements detected in fishmeal and some literature (*g kg^{-1}, mg kg^{-1})

	Fishmeal	Ca *	Na*	K*	P *	Mg *	Fe	Zn	Mn	Cu
Bayrakli ve Duyar (2021)	AM	4.58-7.11	8.09-10.94	26.77-29.46	23.98-26.64	0.26-0.32	2032-2525	232,76-253.04	16.78-20.12	2.21
Satoh, et al. (1987)	SA	44.30	3.20	3.50	27.30	2.00	239	141	11.1	5.4
	Fb-PM	52.20	8.40	3.10	29.30	2.80	97.3	71	5.2	11.5
	BHM	34.40	8.30	13.40	24.70	2.00	289	141	11.1	5.4
Moghaddam, et al. (2007)	SM	39.70	8.30	5.20	26.10	2.70	229	74.5	3.7	6.2
	HM	22.90	6.10	10.90	17.00	1.50	140	132	5	6
	AM	37.30	6.50	6.90	24.30	2.40	220	103	10	9
	MFM	51.10	6.50	6.50	28.80	1.60	440	147	33	11
Storebakken, et al. (2000)	HM	23.90	14.50	12.20	22.10	2.64	155	121	5	3.26
Cho, et al. (1987)	AM	6.77	20.63	7.14		2.22	3598	167		6
Zarkadas et al.(1986)	HM	19.50	4.20	12.00	15.00	1.10	100	100	30	
Irungu et al. (2018)	FWSM	3.93	21.25	10.06	4.40	2.19	922.2	454.9	1932.1	1512.5
This study		27.18	4.58	5.04	23.28	3.16	4050	179.9	56.08	11.67

In the case of SBP-FM, the concentrations of heavy metals As, Pb, Cd, and Hg were determined as 3.51 ± 0.470, 1.46 ± 0.136, 0.15 ± 0.004, and 0.007 ± 0.012 mg kg-1, respectively. No existing literature references were identified for heavy metal results in fishmeal. Therefore, the findings presented in this study could serve as valuable references for future research.

CONCLUSION

This research has examined the nutritional composition of fishmeal produced from fish by-products in seafood processing facilities and demonstrates that this fishmeal could serve as an alternative raw material for sustainable aquaculture. The findings highlight the importance of fishmeal as a significant source of protein for fish nutrition due to its high protein content. Additionally, the energy-providing potential and nutrient profile of fishmeal underline its relevance in the aquaculture sector.

Our study suggests that fishmeal production can be efficiently derived from by-products in seafood processing facilities, which can contribute to reducing environmental impacts and promoting sustainable waste management practices.

Seafood processing facilities should promote the more efficient utilization of fish by-products. This would represent a significant step towards sustainability. Diversifying the raw materials used in fishmeal production and exploring alternative sources can contribute to making the industry more sustainable. However, it's crucial to note that feeding fishmeal derived from salmon processing by-products to salmon may pose a potential risk of cannibalism in salmon populations. Further research is needed to carefully assess and mitigate this risk while considering the environmental impacts of fishmeal production for a more sustainable industry.

This research aims to contribute to the sustainability efforts of the seafood industry. Embracing such alternative approaches to fishmeal production on a larger scale could contribute to the more sustainable use of natural resources and meet the industry's future demands.

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COMPLIANCE WITH ETHICAL STANDARDS

Author Contributions

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Declarations

Ethical approval was not required for this study.

Consent to Participate

As this is a single-authored article, no consent to participate is necessary.

Consent for Publication

Publication consent is not applicable to this study.

Competing Interests

The author declares no competing interests.

Availability of Data and Materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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